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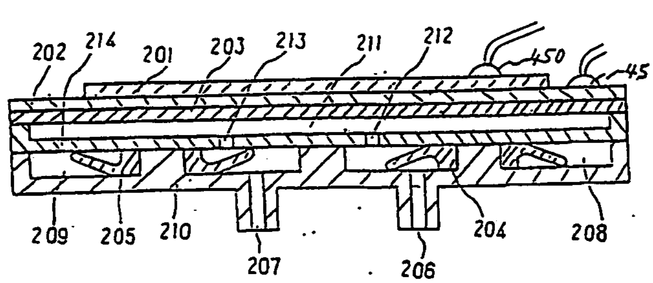
(54) **Micro-pump or micro-discharge device.**

(57) A micro-pump or micro-discharge device comprising piezo-electric means (201) which form part of wall means (201-203) of a liquid reservoir (211), the piezo-electric means (201) being deformable by voltage signals in first and second directions so as respectively to draw liquid into and expel it from the liquid reservoir (211).

Fig. 3



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MICRO-PUMP OR MICRO-DISCHARGE DEVICE.

The present invention relates to a micro-pump or micro-discharge device and, although it is not so restricted, it relates more particularly to a portable micro-pump or micro-discharge device for discharging a liquid at a minute rate either continuously for a predetermined time period, or intermittently.

In the prior art, a micro-discharge device or pump of the kind mentioned above has been disclosed in JP-A-54-12191 and JP-B-61-22599, for example. In the micro-discharge or pump device, as disclosed, an electromagnetic actuator is. used as a prime mover and is coupled to a transmission having a combination of gears of variable sizes so that a syringe may be directly pushed by an arm.

Since, however, this device employs an electromagnetic actuator, it is liable to be affected by electromagnetic noise and consumes a high level of current. Because of using the gears, moreover, the device suffers from considerable variation in its displacement due to backlash, and it also has a complicated structure. Since, furthermore, the syringe is pushed, the overall size of the device is rather large and this restricts its portability.

According to the present invention, there is provided a micro-pump or micro-discharge device comprising piezo-electric means which form part of wall means of a liquid reservoir, the piezo-electric means being deformable by voltage signals in first and second directions so as respectively to draw liquid into and expel it from the liquid reservoir.

In its preferred form, therefore, the present invention provides a small portable micro-discharge device which is substantially unaffected by electromagnetic noise and which has such a small current consumption as to require only a small battery. Thus the device may have excellent portability and discharge accuracy. In its preferred form, moreover, it can be made easy to assemble, free from leakage, and capable of being produced at reduced cost.

Preferably, the liquid reservoir communicates with suction and discharge ports the flow through which is respectively controlled by suction and discharge check valves which are respectively open and closed during liquid inlet to the reservoir and are respectively closed and open during liquid discharge therefrom.

The opening and closing of the check valves may be controlled by the pressure in the liquid reservoir.

The wall means preferably comprises a vibrating diaphragm to which the piezo-electric means are secured.

Thus there may be a metallic electrode plate which is disposed between and is secured to the piezo-electric means and to the diaphragm; and first and second electrodes which are respectively secured to the piezo-electric means and to the metallic electrode plate.

The liquid reservoir may comprise first and second valve chambers which communicate with each other at least at certain times; the first valve chamber having a suction or inlet port and having a suction check valve which is mounted on the first valve chamber and which is adapted to control liquid flow to or through the suction or inlet port; the second valve chamber having a discharge port and having a discharge check valve which is mounted in the second valve chamber and which is adapted to control flow to or through the discharge port. Moreover, the first and second valve chambers may communicate with each other by way of a pressure chamber.

The said wall means may permit communication between the valve chambers only during the said liquid inlet to the liquid reservoir. Thus the diaphragm may be fixed only at its periphery and may be adapted to seal intercommunicable openings in the first and second valve chambers during the said liquid discharge.

In one embodiment, each of the valve chambers, or a space communicating therewith, has a sealing member through which a syringe may be passed to introduce liquid into or withdraw it from the valve chamber.

The check valve may be made of organic material or of a ceramic material which has been etched.

The piezo-electric means may comprise first and second piezo-electric elements which have different directions of polarization.

The diaphragm may comprise a plate of plastics material at least one portion of which is locked in a tapered hole or holes in the electrode plate.

If desired, each check valve comprises a valve member which is urged by a spring towards a closed position.

The or each piezo-electric element may be such that it extends or contracts in radial directions when connected to a suitable control voltage. These extensions and contractions cause the said diaphragm secured to the piezo-electric element to vibrate up and down so as to suck the liquid into the reservoir.

A micro-pump or micro-discharge device using a piezo-electric element can be composed of a smaller number of parts than a discharge device using an electromagnetic actuator so that it can be made small and at reduced production cost. Since,

moreover, the liquid reservoir can be of any shape, there is considerable freedom in designing the device.

Since, furthermore, the piezo-electric element is a voltage-driven actuator, its current consumption can be as small as of the order of microamps. As a result, it is possible to provide a portable micro-pump whose battery has a long lifetime even if this battery is made of lithium.

On the other hand, the flow rate cannot be regulated at every step by a micropump using an electromagnetic actuator. In the present invention, however, the piezo-electric element is used so that the displacement, i.e. the discharge, can be controlled according to the voltage. As a result, the discharge can be controlled according to the frequency, and the flow rate can be controlled at every step according to the voltage so that the discharge can be finely regulated. Moreover, the piezo-electric element can be controlled with a displacement of less than 1 micron, and there is none of the backlash which might otherwise be caused by the gears of the known discharge device using the electromagnetic actuator. If the pressure chamber used has a diameter of 10 mm, for example, the control can be as accurate as the very minute amount of 0.02 micro-litres in terms of the displacement. Since, furthermore, the piezo-electric element is not influenced by the magnetic field, variations in the latter are of no importance, in contrast to the position with an electromagnetic type actuator, so that a high degree of safety can be enjoyed.

The pump may have an integral valve unit in which at least one check valve and a part having a portion forming a passage are combined. Thanks to the use of such valve unit, it is possible to solve the existing problem that a leakage is caused by the ultrasonic energy employed at the time of ultrasonic solvent welding. In the prior art, even one valve, if faulty, can make the two valves and their valve attachments defective. According to this aspect of the present invention, moreover, the valve unit itself can be tested before assembly for its reliability such as leakage. As a result, defective units, if any, can be removed, but only the good units can be reliably assembled into the pump. This reduces the fraction that are defective. In addition, a single valve, which has been difficult to assemble, is divided into valve units so that the defect of one unit will not affect the entirety. Thus, the number of steps is increased by one, but the valve unit becomes easier to assemble. As a result, the reliability and safety can be drastically enhanced from the overall standpoint to reduce the production cost.

When, on the other hand, the valve units are to be assembled into the suction side and the discharge side of the pump, they can be set in position without any consideration as to which side they are supposed to be for.

Since, moreover, different valve units can be used on the suction side and the discharge side, they may be interchanged for the purpose. For a fine flow control, there may be used a valve unit which is composed of a micro-machined ceramic valve. If a low back flow is allowed or if a low production cost is desired, the valve unit may comprise a plastic valve. Thus, it is possible to provide an optimum valve unit for the particular purpose. Standard parts other than the valve units can also be used to reduce costs.

In the designs of the prior art, each pump required a different design. In the case of the present invention, however, it is sufficient to design only the valve units but not the entirety of the pump. Thus, designing is simplified so as to reduce costs substantially.

The pump may be renovated merely by replacing the valve units. The other parts of the pump can be used by changing the valve units at the end of the renovation process. This reduces costs substantially on the part of the manufacturer while causing no confusion in the change of the existing valves on the part of the user. It also increases the value of the warranty of the maker.

As indicated above, a plurality of sheets of piezo-electric ceramic or organic material may be secured to the vibrating diaphragm.

Thus, it is possible to provide a pump unit which has a high flow rate at one step but is hardly influenced by the back pressure. On the other hand, an existing bimorph vibrating diaphragm having piezo-electric elements on opposite sides thereof cannot be used in a corrosive or conductive atmosphere, because it has the piezo-electric element on one side dipped in the liquid so that it is shorted or has its contacts corroded. Since, however, the piezo-electric element secured to one side of the vibrating diaphragm is kept out of contact with the liquid in the pressure chamber, the pump unit can be prevented from being shorted or having its contacts corroded, even if the pressure chamber is in the corrosive or conductive atmosphere, to enhance the reliability of the pump unit and extend its life.

In the pump unit of the micro-pump, the suction valve chamber and the discharge valve chamber may be closed by the vibrating diaphragms, which are held in planar contact with the intervening plate members. As a result, back flow can be eliminated despite some leakage. Moreover, a micro-pump having a low dependency upon the back pressure can be constructed by restricting the displacement of the vibrating diaphragms by the plate members. If, on the other hand, bubbles are

to be withdrawn from the pump unit, this withdrawal is facilitated in the case of a high flow velocity if it is effected under a vacuum or pressure. The bubbles can be easily withdrawn by establishing a space of proper size to be formed by the deformation of the vibrating diaphragms to accelerate the flow velocity.

The liquid can be injected from the outside into the pump and reservoir which have been vacuumized and sealed. If a medical liquid is to be injected for medical purposes directly into the human body, the entry of gases into the medical liquid can be completely prevented to ensure a remarkably high degree of safety.

If a medical liquid or alcohol is used as the liquid to be discharged, the pump unit employed has to be made of a highly chemical-resistant material such as polypropyrene. In this case, the electrode metallic plate and flat polypropyrene plate cannot be secured together by means of an adhesive. In one feature of the present invention, therefore, an electrode metallic plate having tapered holes is insert-molded so as to be united with the vibrating diaphragm. Thus, no separation will occur, whereby a pump unit of excellent durability for repeated use can be provided which has high overall reliability. If, moreover, the vibrating diaphragm is formed with solvent-welding projections, it can be easily welded to the body while ensuring water-resistance, without any use of packings. Thus, a pump unit of which can be easily assembled can be produced at a low cost.

In one embodiment, a first valve member for closing a suction port and a second valve member for closing a discharge opening are urged closed by individual holding springs, the forces of which can be freely set. This makes it possible to set the valve opening pressures freely. When, therefore, the pump is used in a place having many external vibrations, the holding springs may be set to have forces overcoming the vibrations, so that a pump having a more reliable valve structure can be provided. Furthermore, protection against back flow can be drastically improved with excellent contact and sealing properties but without any increase in the back flow rate so that the reliability can be raised to a higher level.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:-

Figures 1 and 2 are a section and a top plan view respectively showing a micro-pump according to a first embodiment of the present invention;

Figure 3 is a section showing a pump unit suitable for use in the micro-pump of Figure 1;

Figure 4 is a block diagram showing a circuit which may be used in the micro-pump of Figure 1;

Figure 5 is a circuit diagram showing one example of a booster circuit which may be used in the micro-pump of Figure 1;

Figure 6 is a circuit diagram showing one example of a level shifter which may be used in the micro-pump of Figure 1,

Figure 7 is a circuit diagram showing one example, of a driver which may be used in the micro-pump of Figure 1;

Figures 8(a) and 8(b) are sections showing the operations of the pump unit of Figure 3;

Figure 9 is a timing chart showing drive signals for the pump unit of Figure 3;

Figures 10 and 11 are a sectional view and a top plan view respectively showing one embodiment of a valve unit;

Figure 12 is a section showing a micro-pump constructed by using the valve unit of Figure 10;

Figures 13(a) and 13(b) are sections showing the operations of the micro-pump of Figure 12;

Figures 14 and 15 are a section and a top plan view respectively showing another embodiment of a valve unit;

Figure 16 is a section showing a micro-pump constructed by using the valve unit of Figure 14;

Figures 17 and 18 are a section and a top plan view showing another embodiment of the valve unit;

Figure 19 is a section showing a micro-pump according to the present invention constructed by using the valve unit of Figure 17;

Figure 20 is a section showing a second embodiment of a micro-pump according to the present invention,

Figure 21 is a characteristic diagram showing the relationship between the back pressure and the flow rate when a bimorph piezo-electric element and a monomorph piezo-electric element are used in a micro-pump according to the present invention;

Figure 22 is a section showing a third embodiment of a micro-pump according to the present invention;

Figures 23(a) and 23(b) are sections showing the operations of the pump of Figure 22;

Figure 24 is a characteristic diagram showing the relationship between the flow rate and the back pressure of the pump of Figure 22;

Figure 25 is a section showing a fourth embodiment of a micro-pump according to the present invention;

Figures 26 and 27 are a top plan view and a section respectively of a seal cap employed in the embodiment of Figure 25;

Figure 28 is a section showing a fifth embodiment of a micro-pump according to the present invention; Figures 29(a) and 29(b) are sections showing the operations of the pump unit of

Figure 25;
Figure 30 is a section showing a sixth embodiment of a micro-pump according to the present invention;
Figures 31 and 32 are a top plan view and a section showing a vibrating diaphragm employed in the embodiment of Figure 30;
Figures 33(a) and 33(b) are sections showing the operation of the pump unit of Figure 30;
Figure 34 is a section showing a seventh embodiment of a micro-pump according to the present invention;
Figures 35(a) and 35(b) are sections showing the operation of the pump unit of Figure 34;
Figure 36 is a section showing an eighth embodiment of a micro-pump according to the present invention;
Figures 37(a) and 37(b) are sections showing the operation of a suction side valve and a discharge side valve, respectively of the embodiment of Figure 36;
Figures 38(a) and 38(b) are respectively sections showing the structure and operations of another valve structure which may be used in the embodiment of Figure 36;
Figures 39(a) and 39(b) are respectively sections showing the structure and operations of yet another valve structure which may be used in the embodiment of Figure 36;
Figure 40 is a side elevation showing how a holding plate and a check valve flapper valve member for the Figure 36 embodiment may be united;
Figure 41 is a section showing a ninth embodiment of a micro-pump according to the present inventionl;
Figures 42(a) and 42(b) are sections showing the operations of the suction side valve and the discharge side valve, respectively of the pump unit of Figure 41;
Figures 43(a) and 43(b) are sections showing the structure and operations of another embodiment of valve structure which may be employed in the Figure 41 embodiment;
Figure 44 is a section showing a tenth embodiment of the structure of the pump unit;
Figures 45(a) and 45(b) are sections showing the operations of a suction side valve and a discharge side valve, respectively employed in the Figure 44 embodiment;
Figures 46(a) and 46(b) are sections showing the structure and operating of another embodiment of a valve structure which may vbe used in the Figure 44 embodiment;
Figures 47(a) and 47(b) are sections showing the structure and operations of yet another embodiment of a valve structure which may be used in the Figure 44 embodiment; and
Figures 48(a) and 48(b) are sections showing the structure and operations of still another embodiment of a valve structure which may be used in the Figure 44 embodiment.

Referring first to Figures 1 and 2, a first embodiment of a micro-pump according to the present invention comprises a pump unit 101 comprising, as described in detail below, a piezo-electric element, a vibrating diaphragm, check valves and a body having a suction port, a discharge port and a passage; an integrated circuit 102 for operating the pump unit 101; a circuit block composed of electric elements such as the integrated circuit 102, a booster coil or capacitor, and a substrate; a battery 104 acting as a power source; an external control switch 105; a reservoir 106; a casing 107; and a display 108.

Figure 3 is a section showing the detail of the pump unit 101. The pump unit 101 comprises piezo-electric element 201, an electrode metallic plate 202, a vibrating diaphragm 203, a suction check valve 204, a discharge check valve 205, an A-body 210, and a B-body 214. The A-body 210 is formed with a suction port 206, a discharge port 207, a suction valve chamber 208 and a discharge valve chamber 209. The B-body forms a pressure chamber 211 together with the vibrating diaphragm 203 and has a suction opening 212 and a discharge opening 213 for providing communications between the pressure chamber 211 and the valve chambers 208 and 209. The B-body is assembled by ultrasonic solvent welding or adhering it to the A-body 210, which has the check valves 204 and 205 mounted therein. The B-body has the vibrating diaphragm 203 which has the piezo-electric element 201 and the electrode metallic plate 202 adhered thereto.

Figure 4 shows one embodiment of the circuit block 103 of Figure 1. This circuit block comprises a power source 301 such as a lithium cell, a booster circuit 302, a CPU 303, a level shifter 304 for transforming a signal of a low voltage to a signal of a high voltage, a driver 305 for driving a piezo-electric element 306, a display 307 for displaying the flow rate or the like of the pump, and a switch 308 for selecting a flow rate or the like. When a flow rate is selected by the switch 308, a pump drive signal is outputted from the CPU 303. Generally speaking, the signal of the CPU 303 operates at a voltage of 3 to 5 V, and the piezo-electric element 306 operates at a high voltage such as 50 V. Thus, the voltage of 3 V, for example, is boosted to 50 V by the booster circuit 302, and the signal from the CPU 303 is transformed to the signal of 50 V by the level shifter 304.

Figure 5 is a circuit diagram showing one example of a chopper type booster circuit for exemplifying the booster circuit 302 of Figure 4. Refer-

ence numerals 401 and 402 designate a pair of input terminals, and numerals 403 and 404 designate a pair of output terminals. The input terminal 401 and the output terminal 403 provide a common electrode Vdd. The input terminal 402 is fed with a low voltage Vssl such as -3V, and the output terminal 404 outputs a high voltage Vssh such as -50 V. Numeral 405 designates a booster coil; numeral 406 designates a first switching element; and numeral 407 designates a control circuit for turning on or off the first switching element 406. Numeral 408 designates a feedback circuit which is composed of resistors 409 and 410. Numeral 411 designates a smoothing capacitor for smoothing the output; numeral 415 designates a reverse-current breaking diode; numeral 412 designates a DC input; numeral 413 designates a DC output; and numeral 414 designates a control signal for controlling the first switching element 406.

If the first switching element 406 is turned on by the control signal 414, the current fed from the DC input 412 begins flowing through the booster coil 405 and the first switching element 406 and increases with time so that an energy proportional to the square of the flowing current value is stored in the booster coil 405.

Next, if the first switching element 406 is turned off, the energy stored in the booster coil 405 is stored in the smoothing capacitor 411 through the reverse-current breaking diode 415. In this case, the reverse-current breaking diode 415 prevents the charge, which is stored in the smoothing capacitor 411, from being released through the first switching element 406 when the switching element 406 is turned on.

The DC output 413 has its voltage divided by the feedback circuit 408, which is composed of the resistors 409 and 410, so that its value is compared with a reference voltage in the control circuit 407. On the basis of this comparison, the control circuit 407 switches the control signal 414 to turn on or off the first switching element 406 so that the DC output 413 may be constant.

Figure 6 is a circuit diagram showing one example of the level shifter 304 of Figure 3. Numeral 421 designates a signal input Vin which is fed with signals at the levels Vdd and Vssl and numeral 422 designates a signal output Vo for outputting signals at the levels Vdd and Vssh. Numeral 423 designates an inverter; numeral 424 designates the level Vdd; numeral 425 designates the level Vssh; numerals 426 and 427 designate P-channel FETs; and numerals 428 and 429 designate N-channel FETs.

If an input signal Vin 421 at the level Vdd is inputted, the transistors 427 and 428 are turned on, but the transistors 426 and 429 are turned off. As a result, the output signal Vo 422 is transformed to a signal at the level Vdd. If, on the other hand, a signal at the level Vssl is inputted as the input signal Vin 421, the transistors 426 and 429 are turned on, but the transistors 427 and 428 are turned off. As a result, the output signal Vo 422 is transformed to a signal at the level Vssh.

Figure 7 is a circuit diagram showing one example of the driver circuit 305 of Figure 4. Numeral 440 designates the input signal Vin; numeral 441 designates an inverter; numerals 442 and 443 designate level shifters; numerals 444 and 446 designate P-channel transistors; numerals 445 and 447 designate N-channel transistors; and numerals 450 and 451 designate the electrodes of the piezo-electric element 201. When a signal at the level Vdd is inputted as the input signal Vin 440, the transistors 444 and 447 are turned off, but the transistors 445 and 446 are turned on. As a result, the electrode 450 has a voltage at the level Vssh, and the electrode 451 has a voltage at the level Vdd. When, on the contrary, a signal at the level Vssl is inputted as the input signal Vin 440, the electrode 450 likewise has a voltage at the level Vdd, and the electrode 451 has a voltage at the level Vssh to drive the piezo-electric element 201.

Figures 8(a) and 8(b) are sections showing the operations of the pump unit 101 of Figure 3. It is assumed that the pressure chamber 211 and the valve chambers 208 and 300 are charged with a liquid. It is also assumed that the piezo-electric element 201 is radially contracted if its upper face electrode 450 is at the voltage Vdd and if its lower face electrode 451 is at the voltage Vssh.

Figure 9 shows drive waveforms of the pump unit 101. Figure 9(a) shows the drive waveform outputted from the CPU 303 of Figure 4; and Figures 9(b) and 9(c) show the drive voltage waveforms to be applied to the electrodes 450 and 451 of Figure 8, respectively. For a time period 901 of Figure 9, the electrode 450 is at the voltage Vdd, and the electrode 451 is at the voltage Vssh, so that the piezo-electric element 201 is radially contracted. As a result of this radial contraction, the vibrating diaphragm 203 is bulged downward, as shown in Figure 8(a). Then, the liquid in the pressure chamber 211 is pressurized to depress the suction check valve 204 so that it is forced to close the suction port 206. At this time, therefore, the liquid is prevented from flowing backward from the pressure chamber 211 to the suction port 206 by the action of the suction check valve 204. At the same time, the pressurized liquid in the pressure chakmber 211 depresses the discharge check valve 205 so as to open the discharge opening 213 and allow the liquid to be pumped out through the discharge port 207 which is not obstructed by the discharge check valve 205.

Next, for a time period 902 of Figure 9, the

electrode 450 is at the voltage Vssh, and the electrode 451 is at the voltage Vdd so that the piezo-electric element 201 is radially extsended. As a result of this extension, the vibrating diaphragm 203 is bulged upward, as shown in Figure 8(b). Then, the liquid in the pressure chamber 211 is vacuumized to pull the suction check valve 204 upward so that it is forced away from the suction port 206 and so as to allow liquid to be sucked into the pressure chamber 211 since the suction check valve 204 will not obstruct the suction opening 212. At this time, the liquid is prevented from flowing from the pressure chamber 211 to the discharge port 207 by the action of the discharge check valve 205 which will close the discharge opening 213.

Thus, the liquid can be pumped from the suction port 206 to the discharge port 207 by repeating the operations thus far described with reference to Figures 8(a) and 8(b).

Figure 10 is a section showing one embodiment of a valve unit which may be used in a micro-pump according to the present invention, and Figure 11 is a top plan view of the same. This valve unit, as generally designated at 220, is constructed of a check valve 221; a D-body 224 having a passage opening 222a and a check valve guide dowel 223; and an E-body 226 (also acting as a passage opening 225) for fixing the check valve. The valve unit 220 thus constructed is assembled in the following manner. First of all, the check valve 221 is set on its guide dowel 223 of the D-body 224. Then, the check valve 221 covers the passage opening 222. After this, the E-body 226 is ultrasonically solvent-welded to the D-body 224 to assemble the valve unit 220.

The check valve 221 is formed into a cap shape, and the check valve guide dowel 223 and the corresponding opening of the check valve 221 are so interconnected that the check valve 221 may not be turned when in the solvent-welding operation.

Figure 12 is a section showing a second embodiment of a micro-pump according to the present invention which is constructed by using valve units 220 as shown in Figures 10 and 11 at the suction and discharge port sides.

In this micro-pump, an A-body 250 is formed with the suction port 206, the discharge port 207, a suction side valve unit receptacle 220a and a discharge size valve unit receptacle 220b. The valve unit 220 is set in its suction side receptacle 220a, whereupon the passage opening 222a of the D-body of the valve unit (as shown in Figure 10) and the suction port 206 of the A-body 250 are aligned. The valve unit 220 is then set in its discharge side receptacle 220b and is inverted with respect to the suction side, whereupon a passage opening 225b of the E-body of the valve unit and the discharge port 206 of the A-body are aligned. Then the valve units 220 are individually solvent-welded to the A-body 250. After this, the electrode metallic plate 202, having the piezo-electric element 201 secured thereto, is likewise secured to the vibrating diaphragm 203 which may be made of an organic material and is then likewise solvent-welded to the A-body, thus assembling the micro-pump. At this time, the valve units and the vibrating diaphragm 203 thus assembled with the A-body form the pressure chamber 211 therebetween. As seen in Figure 12, the individual portions of the valve unit 220 at the suction side are suffixed by the letter a, and the individual portions of the valve unit 220 at the discharge side are suffixed by the letter b.

Figures 13(a) and 13(b) are sections showing the operations of the micro-pump of Figure 12.

If a voltage is applied to the piezo-electric element 201, as shown in Figure 13(a), the metallic vibrating diaphragm 202 having the piezo-electric element 201 secured thereteo and the organic vibrating diaphragm 203 are deformed in the direction of the arrow. As a result, the fluid in the pressure chamber 211 is pressurized to depress the check valve 221a of the suction side valve unit 220 so that the passage opening 222a is closed to block the fluid flow to the suction side. The check valve 221b of the discharge side valve unit 220 is also depressed to open the fluid opening 222b so that the fluid is pumped to the discharge port 207 through the discharge valve chamber 209, and by way of the passage opening 222b and the passage opening 225b.

Next, if a reverse voltage is applied to the piezo-electric element 201, as shown in Figure 13-(b), the electrode metallic plate 202 and the organic vibrating diaphragm 203 are deformed in the direction of the arrow, i.e. in the direction opposite to that of the case of Figure 13(a). As a result, the pressure chamber 211 is vacuumized so that the check valve 221b of the discharge valve unit 220 is sucked upward to close the passage opening 222b. Moreover, the check valve 221a of the suction side valve unit 220 is sucked upward to open the passage opening 222a so that the fluid flows into the pressure chamber 211 through the suction port 206, the passage opening 222a, the suction chamber 208 and the passage opening 225a.

Thus, the fluid is continuously pumped from the suction port 206 to the discharge port 207 by repeating the operations thus far described with reference to Figures 13(a) and 13(b).

Figure 14 is a section showing another embodiment of the valve unit 220, and Figure 125 is a top plan view of the same. This valve unit 220 is constructed to have a valve 231 which, in the position shown in Figure 14, closes two passage openings 234 and 235 in a wall of the pressure

chamber 211. The construction of a micro-pump using this valve unit at the discharge side of Figure 12 is exemplified by the micro-pump of Figure 16. In this way, another type of micro-pump can be manufactured by interchanging the valve units.

It is also possible to use a valve which is manufactured by using and etching ceramics by the existing micro-machining technology. Such a valve is shown in Figures 17 and 18, in which reference numeral 241 designates a ceramic valve shaped by micro-machining. Moreover, the valve 241 is mounted on a base 243 having a passage 242 to the ceramic valve 241. As in the previous constructions, the motions of the valve are effected by moving a vertically movable portion 241a to open or close the passage 242.

Figure 19 is a section showing a micro-pump which is constructed by using the valve unit of Figures 17 and 18.

This embodiment is provided with a base seat 244 for retaining the base 243 of the discharge side valve in the A-body 250. This base seat 244 is formed with a passage 245 in alignment with the passage 242. In this embodiment, moreover, the suction valve chamber 208 acts as the pressure chamber.

The micro-machined valve can be extremely small to effect a fine flow rate control of sub-micro litres. By using micro-machining technology, moreover, a silicon substrate can be etched to integrate the valve, the vibrating diaphragm and the body. Various other valves and valve units can be conceived by moulding them partially of plastics.

Figure 20 is a section showing a second embodiment of a micro-pump according to the present invention employing a pump unit 101. This embodiment is different from that of Figure 3 in that it is provided with a second piezo-electric element 215 in addition to the first piezo-electric element 201. These two piezo- electric elements 201, 215 are assembled to have different directions of polarization. Moreover, the second piezo-electric element 215 is overlaid by an electrode 452 which is set at a common potential to apply a drive to the electrodes 450 and 451 (wherein the electrodce 452 is set at O V to apply a voltage of 50 V to the electrodes 450 and 451, for example).

The operation of the pump unit of Figure 20 is basically similar to those of Figures 8(a) and 8(b), and consequently a description thereof will be omitted.

Figure 21 is a graph illustrating the relationship between the flow rate and the back pressure of the pump unit of Figure 20. In Figure 21, the flow rate is plotted against the back-pressure. A curve 801 represents the characteristics of the pump unit (according to the embodiment of Figure 3) in the case of a monomorph piezo-electric element using only one sheet of piezo-electric material, and a characteristic curve 802 represents the characteristics of the pump unit of Figure 20.

Generally speaking, the flow rate decreases as the back pressure increases because the displacement of the vibrating diaphragm becomes smaller. By using a bimorph piezo-electric element employing two sheets of piezo-electric material, the displacement is doubled by comparison with that of a monomorph piezo-electric element of the same total thickness because each sheet of the bimorph piezo-electric element has half the thickness of the monomorph. If, moreover, two bimorph piezo-electric elements are arranged parallel to each other, the displacement is four times as large as that of an equivalent monomorph. As a result, the flow rate becomes higher than that of the monomorph. If the bimorph thickness is increased, the vibrating system has its rigidity increased so as to be less influenced by the back pressuwre.

Figure 22 is a section showing a third embodiment of a micro-pump according to the present invention employing the pump unit 101. This pump unit has no part corresponding to the pressure chamber 211 of Figure 3, and the B-body 214a and the vibrating diaphragm 203 have only their peripheries fixed. Thus in the Figure 22 construction, the diaphragm 203 is fixed only at its periphery so as to seal the intercommunicable openings 212, 213 in the wall 214a of the valve chambers 208, 209 during liquid discharge, the diaphragm 203 being bulged upwardly away from the wall 214a during liquid inlet so as to permit communication between the chambers 208, 209 at this time.

Figures 23(a) and 23(b) are sections showing the operations of the pump unit of Figure 22. If the electrode 450 is at the voltage Vssh whereas the electrode 451 is at the voltage Vdd, for example, the piezo-electric element 201 is radially extended so that it is bulged upward, as shown in Figure 23-(b). Then, the clearance between the vibrating diaphragm 203 and the B-body 214a is vacuumized so that they are separated from each other to establish a space 211a. As a result, the liquid in the suction valve chamber 208 is vacuumized to suck the suction check valve 204 upward so that liquid is pumped from the suction port 206 to the aforementioned space 211a. Next, if the electrode 450 is at the voltage Vdd whereas the electrode 451 is at the voltage Vssh, the piezo-electric element 201 is radially contracted so that the vibrating diaphragm 203 would otherwise be bulged downward but has its displacement restricted by the B-body 214a, as shown in Figure 23(a), to eliminate the space 211a. Then, the liquid in the space 211a is pressurized to depress the dishcarge check valve 205 so that it is forced to the discharge port 207. Thus, the liquid can be pumped from the

suction port 206 to the discharge port 207 by repeating the operations thus far described with reference to Figures 23(a) and 23(b).

As will be appreciated, the operations of the suction check valve 204 during the discharge and the operations of the discharge check valve 205 during the suction are similar to those of Figures 8-(a) and 8(b).

Figure 24 is a graph representing the relationship between the flow rate of the pump unit of Figure 22 and the back pressure. In Figure 24, the flow rate is plotted against the back pressure. A curve 803 represents the characteristics when the pressure chamber 211 is formed between the vibrating diaphragm 203 and the B-body 214 (in the embodiment of Figure 3), and a curve 804 represents the characteristics of the pump unit of Figure 22. Generally speaking, the flow rate will decrease with increased back pressure because the displacement of the vibrating diaphragm becomes smaller. Since, however, the B-body 214a plays the role of a stopper, it is possible to provide a pump unit which can discharge a constant flow rate until a certain back pressure is reached.

Figure 25 is a section showing a fourth embodiment of a micro-pump according to the present invention. This embodiment is provided with rubber caps 255 and 256 for sealing the suction port 206 and the discharge port 207, respectively. The caps 255 and 256 are provided with syringes 257 and 258 extending therethrough through which a liquid can be respectively injected into the valve chamber 208 and withdrawn from the valve chamber 209.

Figures 26 and 27 are a top plan view and a section showing the sealing rubber cap 255 or 256. Reference numeral 259 designates a cap which is molded of rubber or synthetic rubber such as silicone. A cap 260 having a hole 261 is made of metal or plastics material for guiding the syringe when a liquid is to be injected therethrough from the outside.

Figure 28 shows a fifth embodiment of a micro-pump according to the present invention in which the suction port 206 of the pump unit and a reservoir 263 are connected through a tube 262 and in which the reservoir 263 is provided with the rubber cap 255 at its portion. Incidentally, numeral 264 designates a plastic ring for retaining the rubber cap 255 in the reservoir 263.

When the micro-pump of Figure 28 is to be used for injecting a medical liquid directly into a human body for medical purposes, for example, it is essential to scavenge the pump and the reservoir 363. Thus, the insides of the pump unit and of the reservoir 363 are evacuated in advance and are sealed up with the sealing rubber caps. Then, the liquid can be injected into the chamber 208 by inserting the syringe 257 from the side into the suction port 206 of the pump unit or into the rubber cap 255 of the reservoir 263 to fill up the inside of the pump or the reservoir exclusively with the liquid. This liquid can be discharged to the outside by the syringe 258.

Figures 29(a) and 29(b) are sections illustrating the operation of the pump unit of Figure 25. If the electrode 450 is at the voltage Vdd whereas the electrode 451 is at the voltage Vssh, the piezo-electric element 201 is radially contracted so that the vibrating diaphragm 203 is bulged downward, as shown in Figure 29(a). Then, the liquid in the pressure chamber 211 is pressurized to depress the discharge check valve 205 so that it is forced to the discharge port 207. Next, if the electrode 450 is at the voltage Vssh, whereas the electrode 451 is at the voltage Vdd, the piezo-electric element 201 is radially extended so that the vibrating diaphragm 203 is bulged upward, as shown in Figure 29(b). Then, the liquid in the pressure chamber 211 is vacuumized to pull the suction check valve 204 upward so that it is forced away from the suction port 206. Thus, the liquid can be pumped from the suction port 206 to the discharge port 207 by repeating the operations thus far described with reference to Figures 29(a) and 29(b).

Figure 30 is a section showing a sixth embodiment of a micro-pump according to the present invention. In this embodiment, the vibrating diaphragm 203 is made of a flat diaphragm 274 of plastics material.

Figures 31 and 32 are respectively a top plan view and a section showing the vibrating diaphragm 203 of Figure 30. Since the electrode metallic plate 202 is formed with tapered holes 270, the plastics flat diaphragm 274 is firmly fixed to the electrode metallic disc 202 by filling up the aforementioned holes with plastics material. Numeral 271 designates a positioning ring of plastics material which is to be used when the piezo-electric element 201 is to be secured. Numeral 272 designates a terminal for soldering the electrode. Numeral 273 designates a projection for effecting ultrasonic solvent welding of the B-body 214 so as to fix it and render it liquid-tight.

Figures 33(a) and 33(b) are sections showing the operation of the pump unit of Figure 30.

When the electrode 450 is at the voltage Vdd whereas the electrode 451 is at the voltage Vssh, the piezo-electric element 201 is radially contracted so that the vibrating diaphragm 203 is bulged downward, as shown in Figure 33(a). Then, the liquid in the pressure chamber 211 is pressurized to depress the discharge check valve 205 so that it is forced towards the discharge port 207. Next, when the electrode 450 is at the voltage Vssh whereas the electrode 451 is at the voltage Vdd, the piezo-electric element 201 is radially extended

so that the vibrating diaphragm 203 is bulged upward, as shown in Figure 33(b). Then, the liquid in the pressure chamber 211 is vacuumized to pull the suction check valve 204 upward so that it is forced from the suction port 206 and towards the pressure chamber 211. Thus, the liquid can be pumped from the suction port 206 to the discahrge port 207 by repeating the operations thus far described with reference to Figures 33(a) and 33(b).

Figure 34 is a section showing a seventh embodiment of the pump unit 101. This pump unit is constructed of the piezo-electric element 201, the electrode metallic plate 202, the vibrating diaphragm 203 and the B-body 214. To the lower side of the B-body 214, there are attached an F-body 290 and a G-body 291. The F-body 290 is formed with the suction side valve chamber 208, in which are housed a resilient flapper valve member 284 for the suction side check valve, a suction side check valve holding spring 285, and a holding plate 286 mounted for causing the holding spring 285 to hold the resilient flapper valve member 284 straight. On the other hand, the G-body 291 is formed with the discharge side valve chamber 209, in which are housed a resilient flapper valve member 287 for the discharge side check valve, a discharge side check valve holding spring 288, and a holding plate 289 mounted for causing the holding spring 288 to hold the elastic flapper valve member 287 straight. To the lower side of the F-body 290 and the G-body 291, there is attached an H-body 292 which is formed with the suction port 206 and the discharge port 207.

In order to assemble the structure shown in Figure 34, first of all, the elastic flapper valve member 284 and the holding palte 286 are set in the suction port 206 of the H-body 292, and the F-body 290 and the G-body 291 are ultrasonically solvent-welded to the H-body 292. After this, the holding spring 285 is put into the suction side valve chamber 208, and the holding spring 288 is put into the discharge side valve chamber 209. After this, the holding palte 289 and the elastic flapper valve member 287 are put into the discharge side valve chamber 209. Then, the B-body 214 is ultrasonically solvent-welded downward to the F-body 290 and the G-body 291. After this, the vibrating diaphragm 203 having the piezo-electric elment 201 and the electrode metallic plate 202 are likewise ultrasonically solvent-welded to the B-body 214, thus assembling the pump unit.

In the embodiment of Figure 34, the resilient flapper valve members 284 and 287 are normally disc-shaped. The holding plates 286 and 289 are also normally disc-shaped. The holding springs 285 and 288 are further normally formed as cylindrical coils. In this case, the elastic flapper valve members 284 and 287 are made of silicone rubber or neoprene rubber but may be made of another material if this material is resilient. The holding plates 286 and 289 are made of an organic material such as plastics or a metallic material such as stainles steel. The material for the holding springs 285 and 288, however, is not limited to metallic materials but may also be of organic material.

In the embodiment of Figure 34, on the other hand, the holding springs 285 and 288 act to hold the elastic flapper valve members 284 and 287 through the holding plates 286 and 289 so that the elastic flapper valve members 284 and 287 are caused to close the suction side suction port 212 or the (discharge side) discharge port 213 thereby to act as valves while preventing back flows. In this case, if the flapper valve member 284 (or 287) can be held to apply a force, which is uniform circumferentially of the suction port 212 (or discharge port 213), at its face contacting the suction port 212 (or discharge port 213), it will be appreciated that the holding spring 285 (or 288) may hold the resilient flapper valve member 284 (or 287) not through the holding plate 285 (or 289) but directly.

Figures 35(a) and 35(b) are sections showing the operation of the pump unit of Figure 34.

When the electrode 450 is at the voltage Vdd whereas the electrode 451 is at the voltage Vssh, the piezo-electric element 201 is radially contracted so that the vibrating diaphragm 203 is bulged downward, as shown in Figure 35(a). Then, the liquid in the pressure chamber 211 is pressurized to exceed the force set by the holding spring 288. Then, the pressure depresses the resilient flapper valve member 287 for the discharge side check valve, the holding palte 289 and the holding spring 288 so that the liquid is forced from the discharge opening 213 and thus through the valve chamber 209 to the discharge port 207. At the suction side, on the contrary, the resilient flapper valve member 284 for the suction side check valve is urged to hold the suction port 206 closed through the holding plate 286 by the action of the holding spring 285, so that there is no back flow of the liquid from the pressure chamber 211 to the suction port 206.

Next, when the electrode 450 is at the voltage Vssh whereas the electrode 451 is at the voltage Vdd, the piezo-electric element 201 is radially extended to bulge the vibrating diaphragm 203 upward, as shown in Figure 35(b). Then, the liquid in the pressure chamber 211 is vacuumized to exceed the force which is set by the holding spring 285. Then, the liquid pushes up the resilient flapper valve member 284 for the suction side check valve, the holding plate 286 and the holding spring 285 so that it is forced through the suction port 205 to the valve chamber 298 and through the suction opening 212 to the pressure chamber 211. At the discharge side, on the contrary, the resilient flapper

valve member 287 for the discharge side check valve is urged to hold the discharge opening 213 closed through the holding plate 289; by the action of the holding spring 288. Consequently, there is neither a flow of the liquid from the pressure chamber 211 to the discharge port 207 nor is there a back flow from the discharge port 207 to the pressure chamber 211.

Thus, the liquid can be forced from the suction port 206 to the discharge port 207 by repeating the operations thus far described with reference to Figures 35(a) and 335(b).

Figure 36 is a section showing an eighth embodiment of a micro-pump employing the pump unit 101. In this embodiment, one sheet of a resilient member 293 having a hole 294 therein is sandwiched between the resilient flapper valve member 284 for the suction side check valve and the suction port 206. In this case, the resilient member 293 is formed of a stepped disc made of silicone rubber and is fixedly sandwiched between the F- body 290 having the valve chamber 208 and the H-body 292 having the suction port 206.

In the embodiment of Figure 34, the H-body having the suction port 206 is made of plastics and is constructed to block the back flow by face-to-face contact with the resilient flapper valve member 284 for the suction side check valve. In the embodiment of Figure 36, on the other hand, the contacting faces are made of rubber. As a result, the degree of contact can be enhanced to block the back flow more reliably. A similar structure is provided at the discharge side.

Figure 37(a) is a section showing the actions of the valve at the suction side of the pump of Figure 36. As shown, the liquid is forced from the suction port 206 through the valve chamber 208 to the suction opening 212. A clearance is established by the action of the piezo-electric element 201 between the resilient flapper valve member 284 for the suction check valve and the resilient member 293 which had been held in close contact with each other to pass the liquid therethrough. Figure 37(b) is a section showing the operation of the valve at the discharge side which corresponds to the operation at the suction side.

Figure (38a) is a section showing another embodiment of the valve structure which may be used in the embodiment of Figure 36. In the valve structure of this embodiment, a ridged portion 395 rising from around the suction port 206 is formed at the contacting portions of the flapper valve member 284 for the suction side check valve and the suction port 206. The contact effected by the flapper valve member 284 for the suction side check valve is changed from a facial to a linear one so that the back flow can be blocked even with an inferior facial accuracy of the contact.

Figure 38(b) is a section showing the operation of the valve of Figure 38(a). A clearance is established between the ridged portion 295 and the flapper valve member 284 for the suction side check valve to pass the liquid therethrough. The suction side valve structure described above is likewise applied to the discharge side.

Figure 39 is a section showing another embodiment of the valve structure which may be used in the embodiment of Figure 36. Figure 39(a) shows the structure of a ridged portion 296 which extends around the suction port 206, the ridged portion 296 being a portion of the flapper valve member 284 for the suction side check valve. Figure 39(b) shows the operation of the valve thus formed. The liquid is allowed to flow if a clearance is established between the ridged portion 296 and the suction port 206.

In the embodiments of Figures 34-39, the holding plate 286 (or 289) and the check valve flapper valve member 284 (or 287) is disc-shaped so that they may be aligned with one on top of the other. As shown in Figure 40, however, a stable flapper valve member for the check valve can be achieved if a holding plate 297 and a check valve flapper valve member 298 are constructed to interengage each other.

Figure 41 is a section showing a ninth embodiment of a micro-pump according to the present invention employing the pump unit 101. This embodiment is basically similar in structure to that of Figure 34, except that the check valve flapper valve member 284 (or 287) of Figure 34 is replaced by a round ball 501 (and 502) for releasably holding the suction port 206 and the discharge opening 213 closed. The round ball to be used here may be made of an inorganic material such as steel, ceramics or glass, or an organic material such as plastics or rubber. The holding plate 286 (or 289) is inserted so that it may push against the suction port 206 (or the discharge opening 213) with an uniform force and so that it may return the ball 501 (or 502) to its normal position (to close the suction port 206 or the discharge opening 123) if it is dislodged from the suction port 206 (or the discharge opening 213).

For this purpose, the holding plate 286 (or 289) used is made of a plate having a smaller coefficient of friction than that of the ball.

Figure 42(a) shows the operation of the suction side valve of the pump unit of Figure 41. The liquid is passed through the clearance which is established between the suction port 206 and the ball 501. Figure 42(b) shows the operation of the discharge side valve of the pump unit of Figure 41. The liquid will flow through the clearance between the discharge opening 213 and the ball 502. In any event, the overall operations of the pump are simi-

lar to those described with reference to Figures 35-(a) and 35(b).

Figure 43(a) is a section showing another embodiment of a valve structure which may be used in the Figure 41 embodiment. The portion of the suction port 206 to come into contact with the ball 501 is conically recessed, as indicated at 503. Since the ball position is stabilized by this structure (that is, the ball is directed to the centre of the suction port if it rolls), a more reliable valve structure is obtained.

Figure 43(b) shows the operation of the valve structure of Figure 43(a). The liquid is also passed through a clearance which is formed during liquid inlet between the ball 501 and the conical portion 503. The structure of the embodiment of Figure 43 can be likewise applied to the discharge side valve.

Figure 44 is a section showing a tenth embodiment of a micro-pump according to the present invention employing the pump unit 101. This embodiment is basically similar to that of Figure 36 but uses the ball 501 (or 502) in place of the check valve flapper valve member 284 (or 287). According to this construction, a highly reliable valve can be achieved by the action of a stepped disc-shaped resilient member 504 or 506 because the ball 501 (or 502) is brought into close contact by the elasticity of the resilient member even if the ball has a poor roundness or a high hardness and a rough surface.

Figures 45(a) and 45(b) show the operations of the balls 501 and 502 at the suction and discharge sides and are similar to Figures 37(a) and 37(b) or Figures 42(a) and 42(b).

Figures 46(a) is a section showing another embodiment of a valve structure which may be used in the Figure 44 embodiment. The construction is such that the portion of the suction port 206 to come into contact with the ball 501 is formed therearound with a round groove 508 in which an O-ring 509 is fixed. The O-ring 509 is made of a resilient material such as a silicone or neoprene rubber. As a result, there can be provided a structure for blocking the back flow by the close contact between the ball 501 and the O-ring 509.

Figure 46(b) is a section showing the operations of the ball valve 501. The liquid will be passed through a clearance, if any, between the O-ring 509 and the ball 501. The valve structure of Figure 46 can be likewise applied to that of the discharge side.

Figure 47(a) is a section showing another embodiment of a valve structure which may be used in the Figure 44 embodiment. In this embodiment, the ball is not a completely round one but a semi-spherical member 510 having a flat surface in contact with the holding plate 286 and a semi-spherical surface contacting the suction port 206. Alternatively, the holding plate 286 and the semi-spherical member 510 may be secured to each other so that they be used integrally as a unit.

Figure 47(b) is a section showing the operations of the semispherical member 510. The liquid will be passed through a clearance, if any, between the suction port 206 and the semispherical member 510. The valve structure of Fifgure 47 can be likewise applied to the discharge side valve structure.

Figure 48(a) is a section showing another embodiment of a valve structure which may be used in the Figure 44 embodiment. This embodiment is such that the suction port 206 is normally held closed by a conical member 511. The conical member 511 and the holding plate 286 can also be secured to each other so that they may be used integrally as a unit.

Figure 48(b) is a section showing the operations of the conical member 511. The liquid will also be passed through a clearance, if any, between the suction port 206 and the conical member 511. The valve structure of Figure 48 can be likewise applied to the valve structure at the discharge side.

Claims

1. A micro-pump or micro-discharge device comprising piezo-electric means (201) which form part of wall means (201-203) of a liquid reservoir (211), the piezo-electric means (201) being deformable by voltage signals in first and second directions so as respectively to draw liquid into and expel it from the liquid reservoir (211).

2. A micro-pump or micro-discharge device as claimed in claim 1 characterised in that the liquid reservoir (211) communicates with suction and discharge ports (206,207) the flow through which is respectively controlled by suction and discharge check valves (204,205) which are respectively open and closed during liquid inlet to the reservoir (211) and are respectively closed and open during liquid discharge therefrom.

3. A micro-pump or micro-discharge device as claimed in claim 2 characterised in that the opening and closing of the check valves (204,205) is controlled by the pressure in the liquid reservoir (211).

4. A micro-pump or micro-discharge device as claimed in any preceding claim characterised in that the wall means (201-3) comprises a vibrating diaphragm (203) to which the piezo-electric means (201) are secured.

5. A micro-pump or micro-discharge device as claimed in claim 4 comprising a metallic electrode plate (202) which is disposed between and is se-

cured to the piezo-electric means (201) and to the diaphragm (203); and first and second electrodes (450,45) which are respectively secured to the piezo-electric means (201) and to the metallic electrode plate (202).

6. A micro-pump or micro-discharge device as claimed in any preceding claim characterised in that the liquid reservoir comprises first and second valve chambers (208,209) which communicate with each other at least at certain times; the first valve chamber (208) having a suction or inlet port (206) and having a suction check valve (204) which is mounted in the first valve chamber (208) and which is adapted to control liquid flow to or through the suction or inlet port (207); the second valve chamber (209) having a discharge port (207) and having a discharge check valve (205) which is mounted in the second valve chamber (209) and which is adapted to control flow to or through the discharge port (207).

7. A micro-pump or micro-discharge device as claimed in claim 6 characterised in that the first and second valve chambers (208,209) communicate with each other by way of a pressure chamber (211).

8. A micro-pump or micro-discharge device as claimed in claim 6 or7 characterised in that the suction check valve (221a) and a part (224a) forming the first valve chamber are united into a first valve unit (220a), and the discharge check valve (221b) and a part (224b) forming the second valve chamber are united into a second valve unit (220b).

9. A micro-pump or micro-dicharge device as claimed in claim 8 characterised in that said first valve unit (220a) and said second valve unit (220b) have different valve structures.

10. A micro-pump or micro-discharge device as claimed in claim 6 characterised in that the said wall means (201-203) permit communication between the valve chambers (208,209) only during the said liquid inlet to the liquid reservoir.

11. A micro-pump or micro-discharge device as claimed in claim 10 when dependent upon claim 4 in which the diaphragm (203) is fixed only at its periphery and is adapted to seal intercommunicable openings (212,213) in the first and second valve chambers (208,209) during the said liquid discharge.

12. A micro-pump or micro-discharge device as claimed in any of claims 6, 10 or 11 characterised in that each of the valve chambers (208,209), or a space (263) communicating therewith, has a sealing member through which a syringe (257,258} may be passed to introduce liquid into or withdraw it from the valve chamber.

13. A micro-pump or micro-discharge device as claimed in any preceding claim characterised in that the check valves (204,205) are made of a ceramic material which has been etched.

14. A micro-pump or micro-discharge device as claimed in any preceding claim characterised in that the piezo-electric means comprise first and second piezo-electric elements (201,215) which have different directions of polarization.

15. A micro-pump or micro-discharge device as claimed in claim 5 or in any claim appendant thereto characterised in that the diaphragm (203) comprises a plate (274) of plastics material at least one portion of which is locked in a tapered hole or holes (270) in the electrode plate (202).

16. A micro-pump or micro-discharge device as claimed in any preceding claim characterised in that each check valve comprises a valve member (284,287) which is urged by a spring (285,288) towards a closed position.

17. A micro-pump comprising: a piezo-electric element made deformable if fed with a control voltage; a vibrating diaphragm having said piezo-electric element adhered thereto so that it can be deformed in accordance with the deformation of said piezo-electric element; a suction check valve for releasing the closure of a suction port in accordance with the deformation of said vibrating diaphragm in a predetermined direction, to such a liquid from said suction port; and a discharge check valve for releasing the closure of a discharge opening in accordance with the deformation of said vibrating diaphragm in the direction opposite to the first-named direction, to discharge the liquid, which is sucked from said suction port, from a discharge port through said discharge opening.

18. A micro-discharge device comprising: a pump unit for discharging a liquid at a micro-rate in accordance with the displacement of a vibrating diaphragm which is deformed as a piezo-electric element is deformed; a control circuit unit for operating and controlling said pump unit; and a power source unit for supplying an electric power to said pump unit and said control circuit unit, wherein said pump unit, said control circuit unit and said power source unit are housed in a casing.

Fig. 1

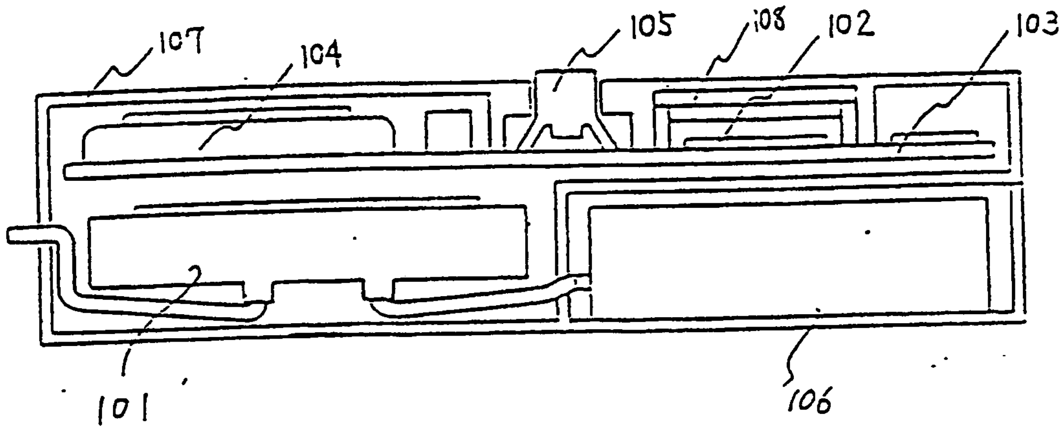


Fig. 2

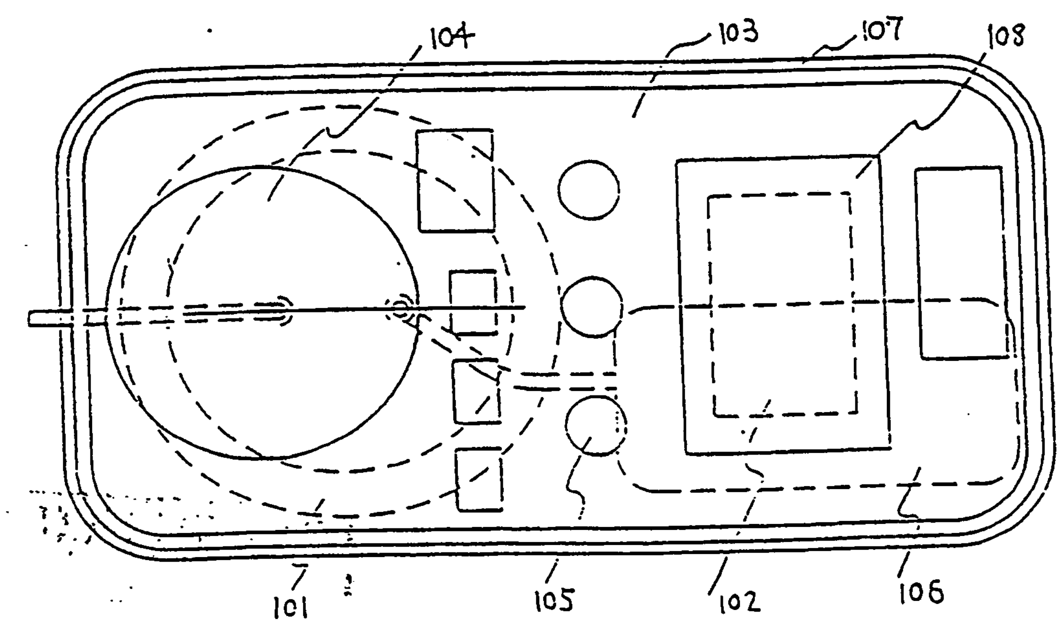


Fig. 3

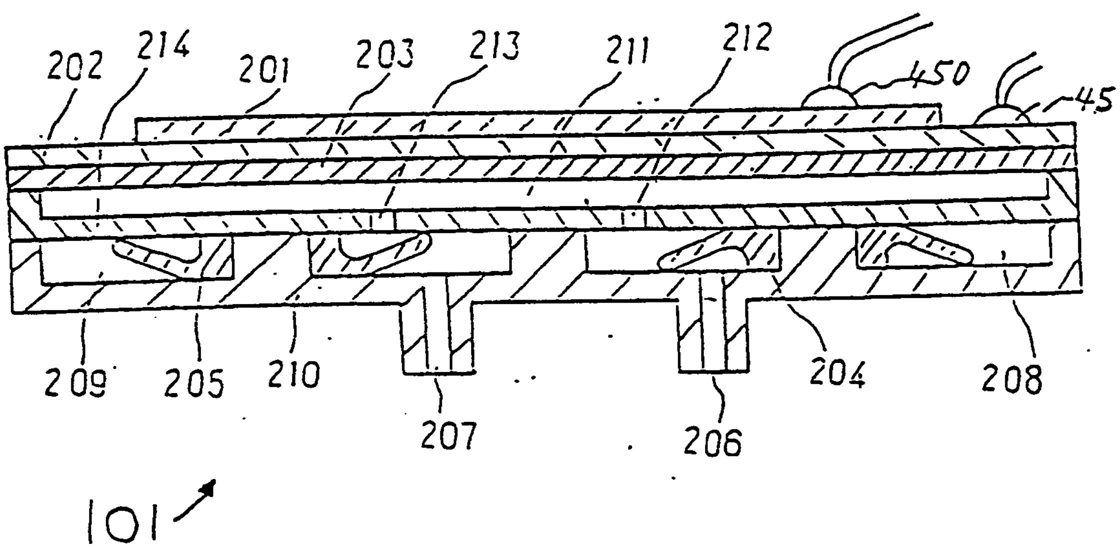

202
214
201
203
213
211
212
450
45
209
205
210
207
206
204
208
101

Fig. 4

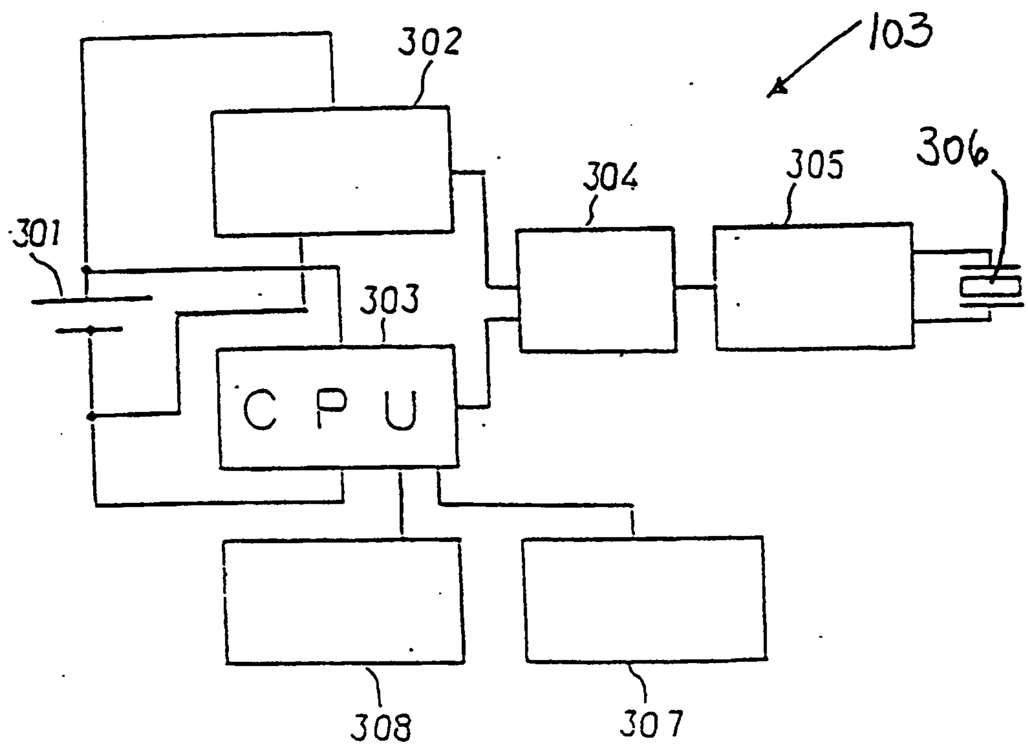


Fig. 5

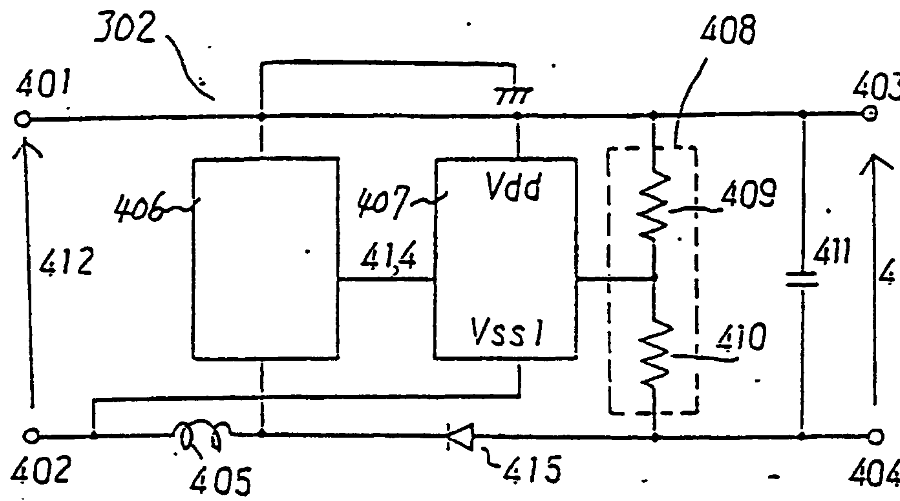
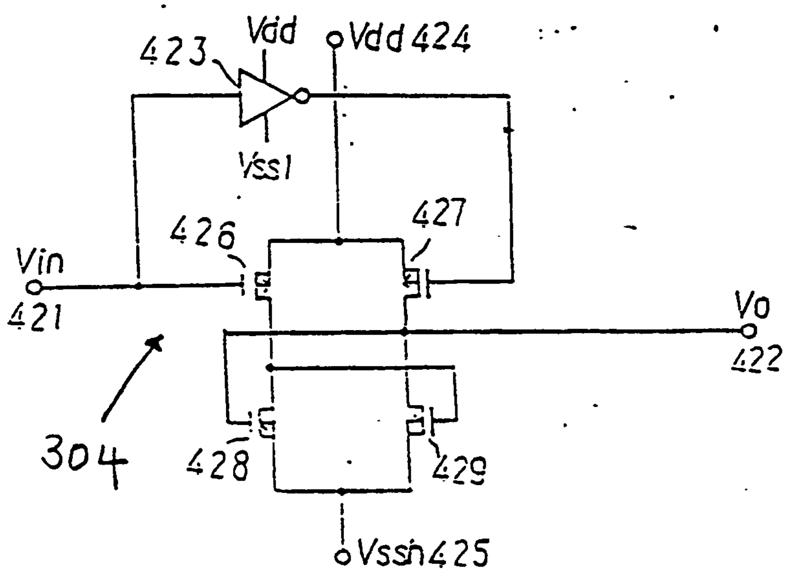

302
401
408
403
406
407
Vdd
409
412
41,4
411
413
Vss1
410
402
405
415
404

Fig. 6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Vdd 424
Vss1
426
427
Vin
421
Vo
422
304
428
429
Vssh 425

Fig.7

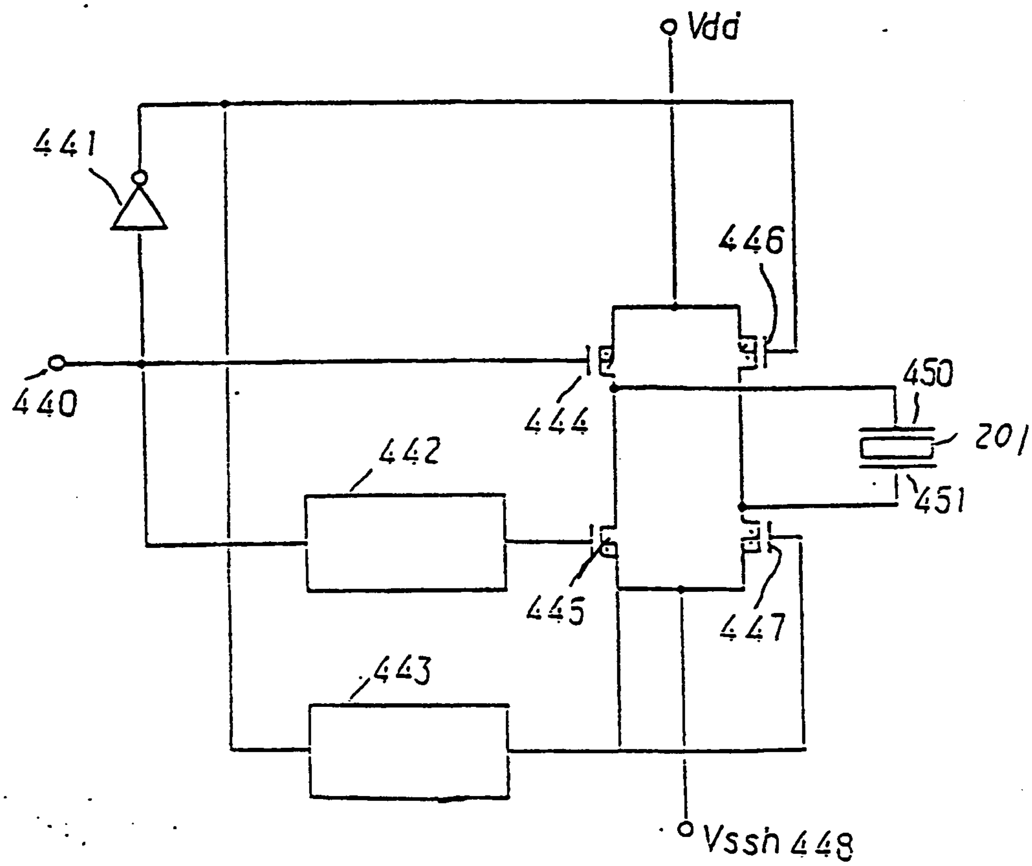
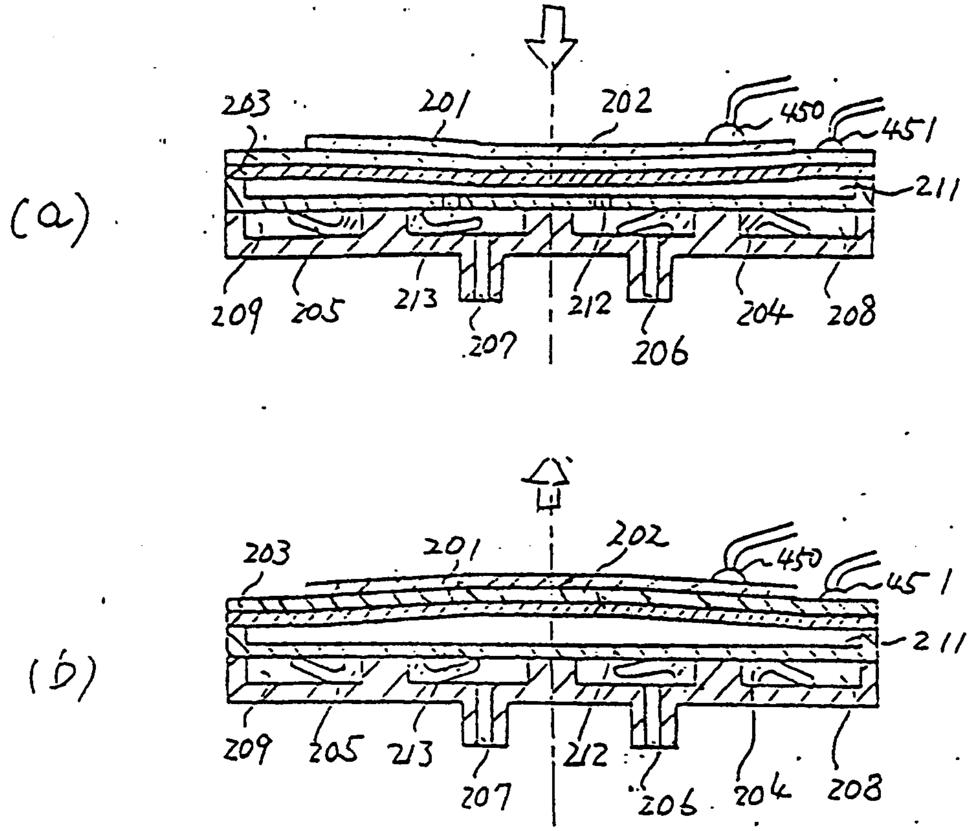
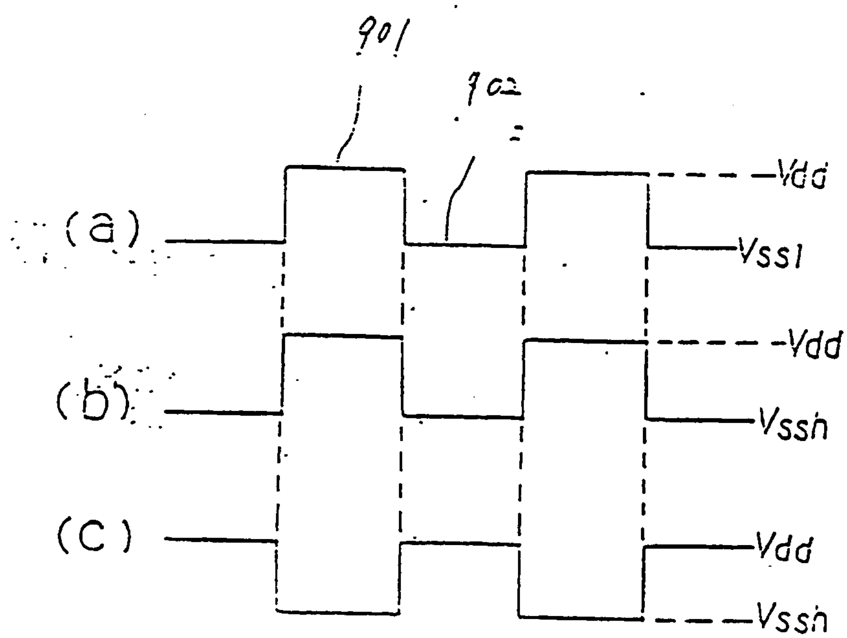


FIG. 8.



(a)
203
201
202
450
451
211
209
205
213
207
212
206
204
208
(b)
203
201
202
450
451
211
209
205
213
207
212
206
204
208

Fig. 9



901
902
(a)
Vdd
Vssl
(b)
Vdd
Vssh
(c)
Vdd
Vssh

Fig. 10

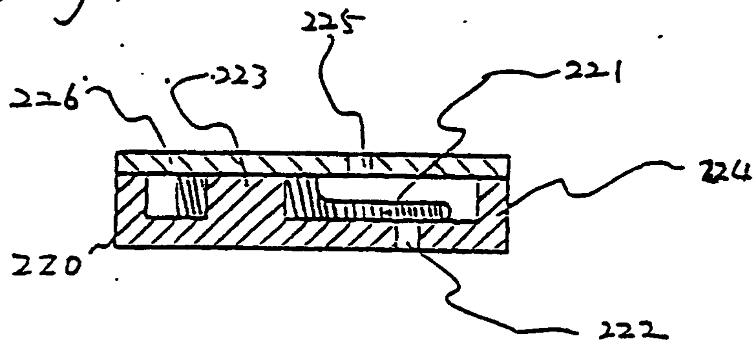


Fig. 11

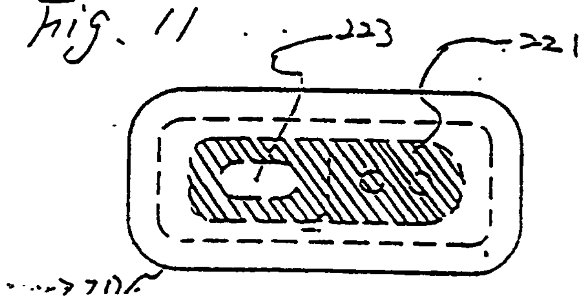


Fig.12

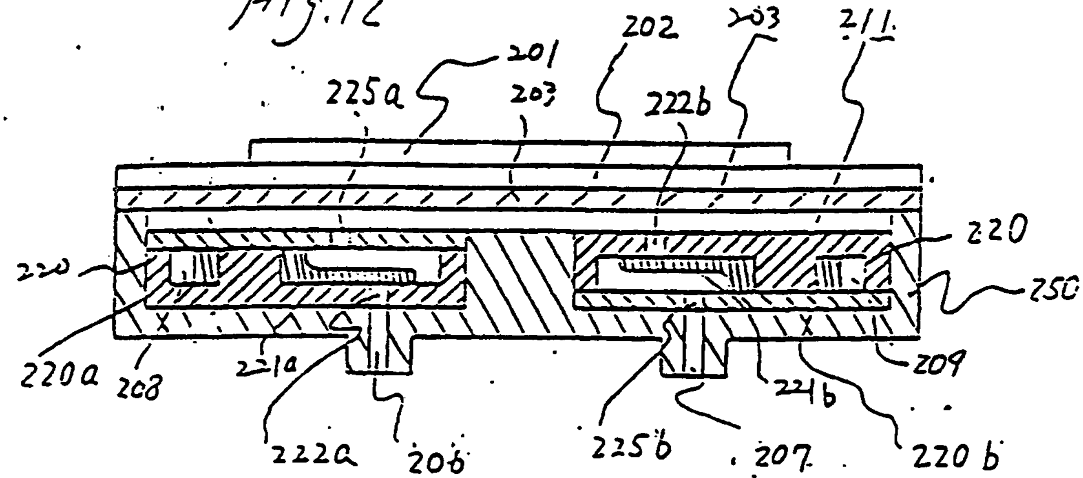
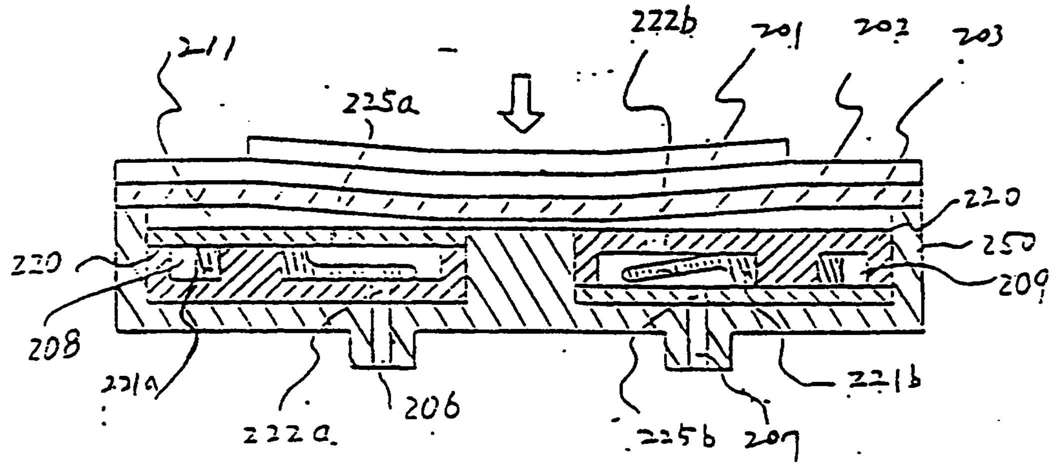


Fig.13

(a)



(b)

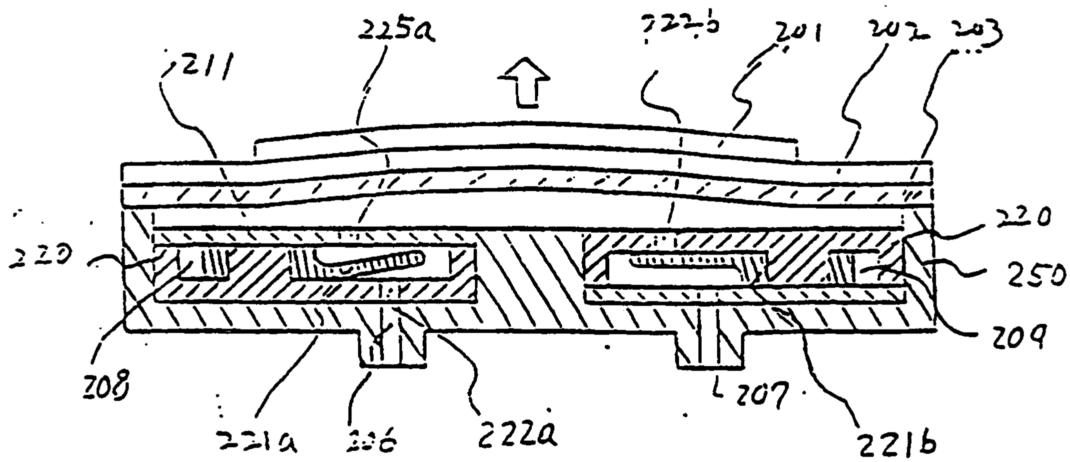


Fig. 14

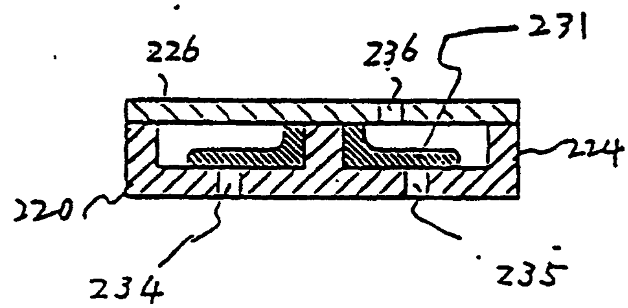


Fig. 15

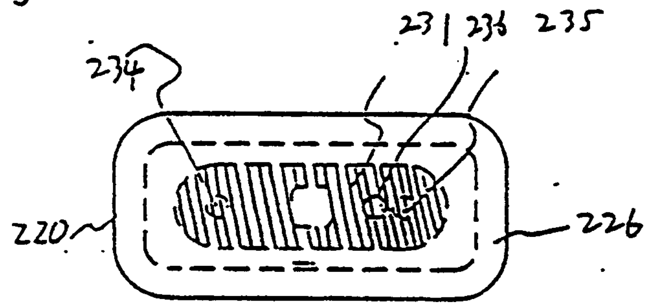


Fig. 16.

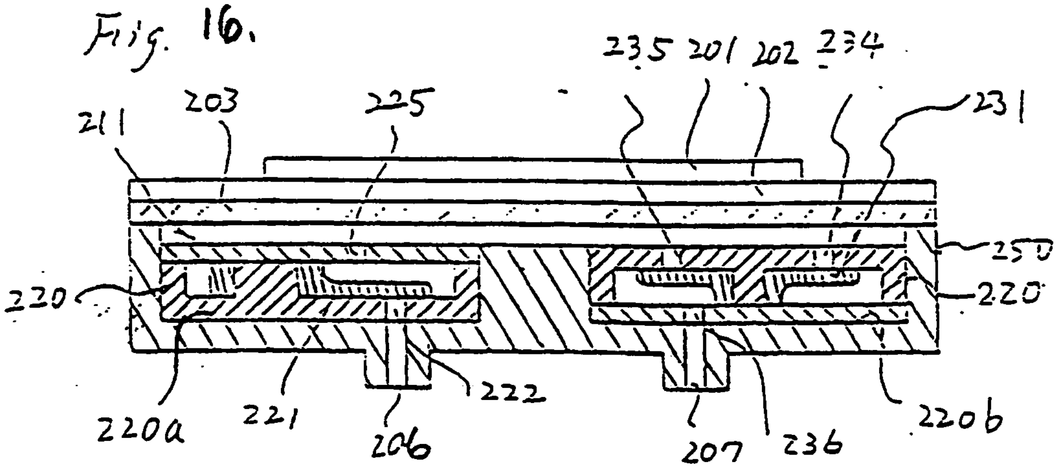


Fig. 17

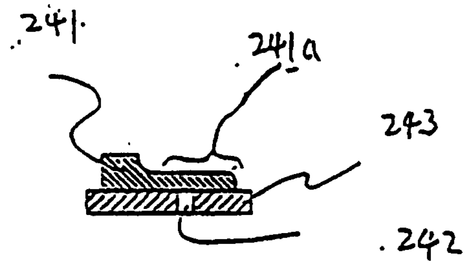


Fig. 18

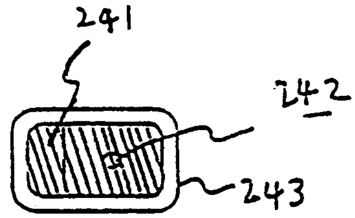


Fig. 19

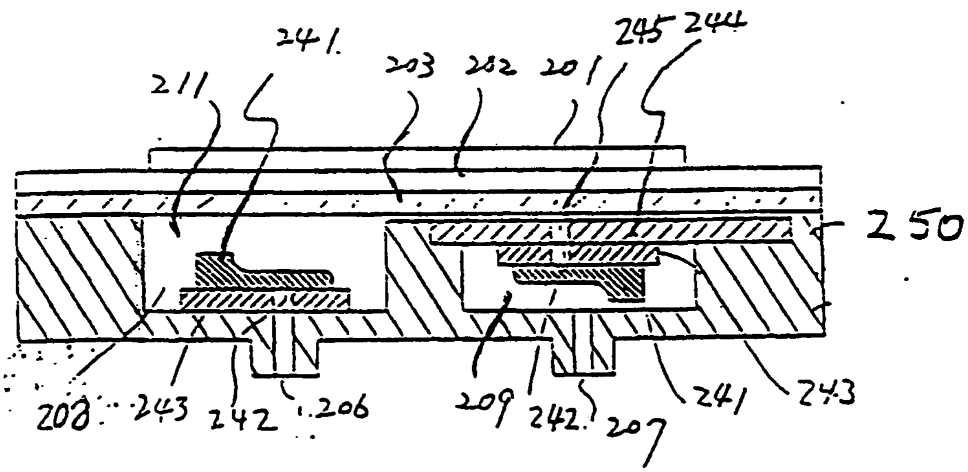


Fig. 20

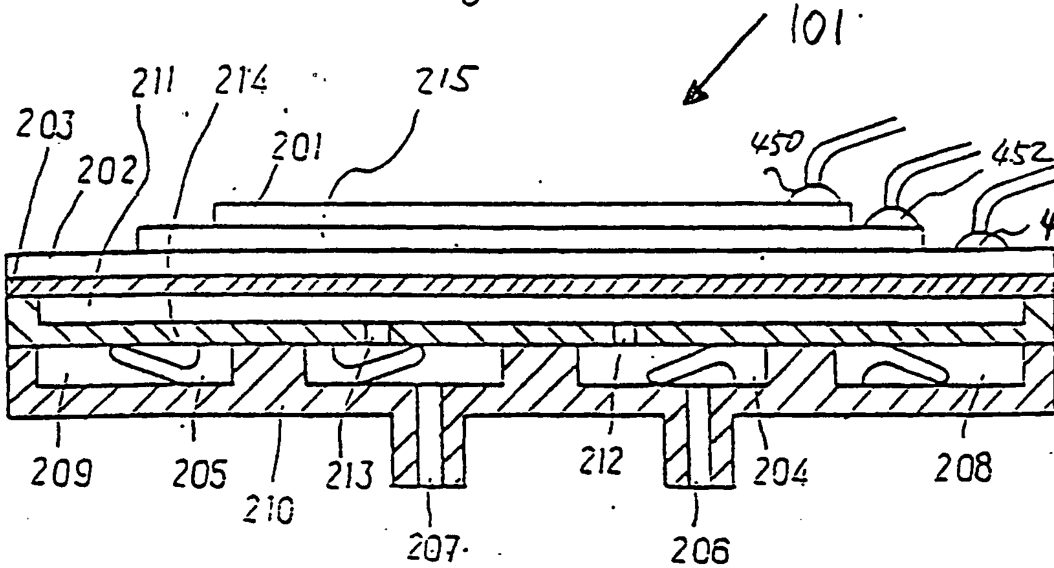

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Fig. 21.

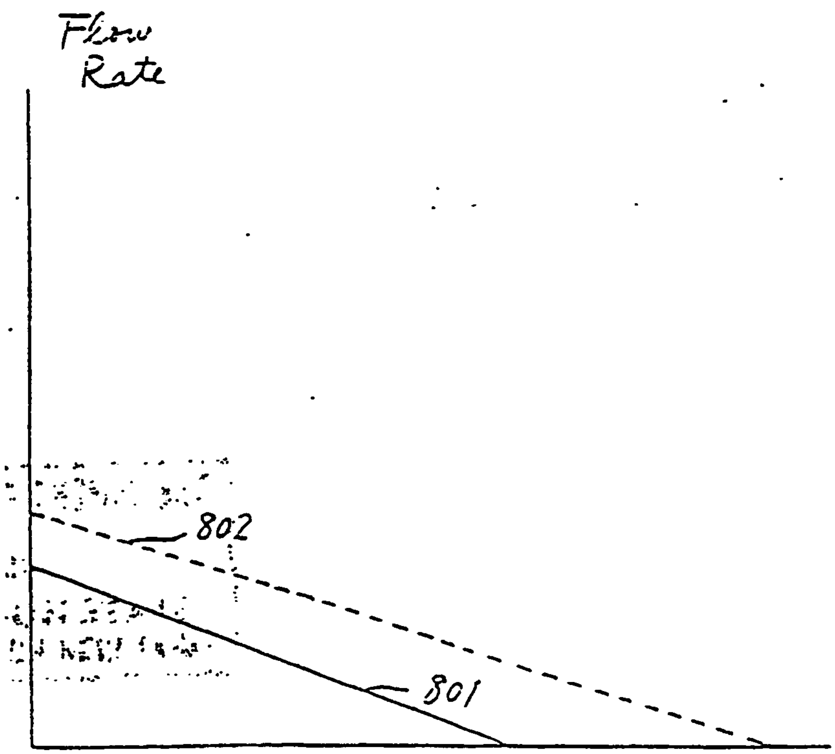

Flow Rate
802
801

Fig 22.

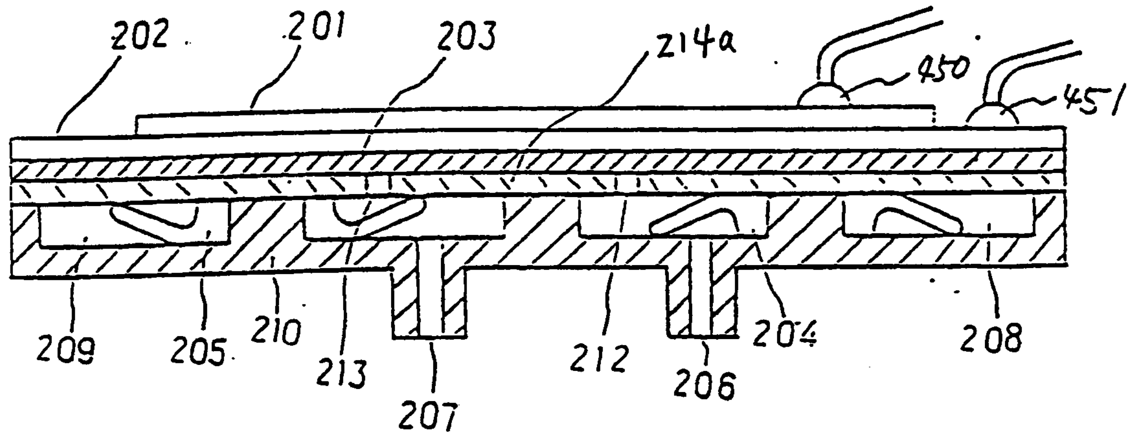
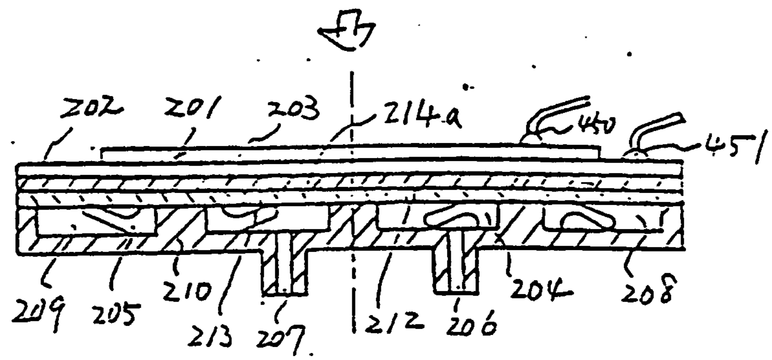
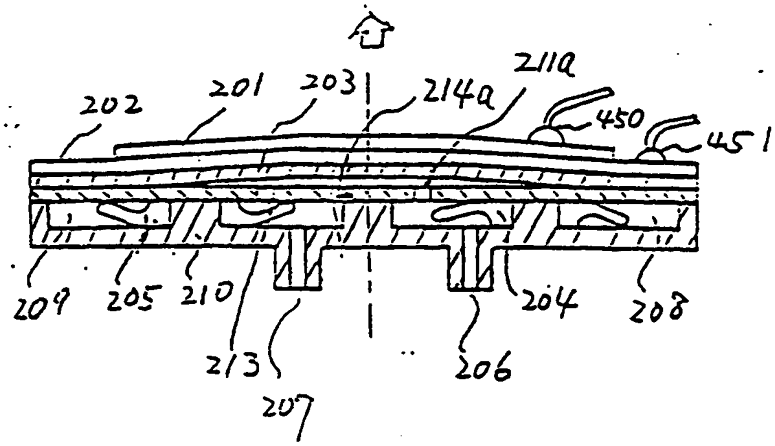


FIG. 23

(a)



(b)



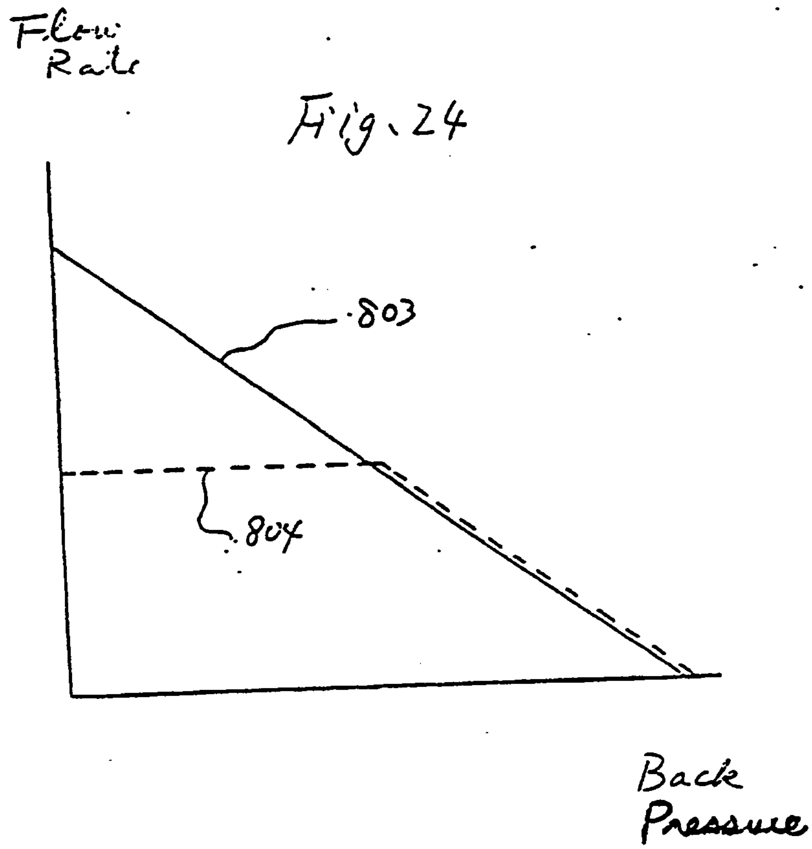

Flow Rate
Fig. 24
803
804
Back Pressure

Fig.25

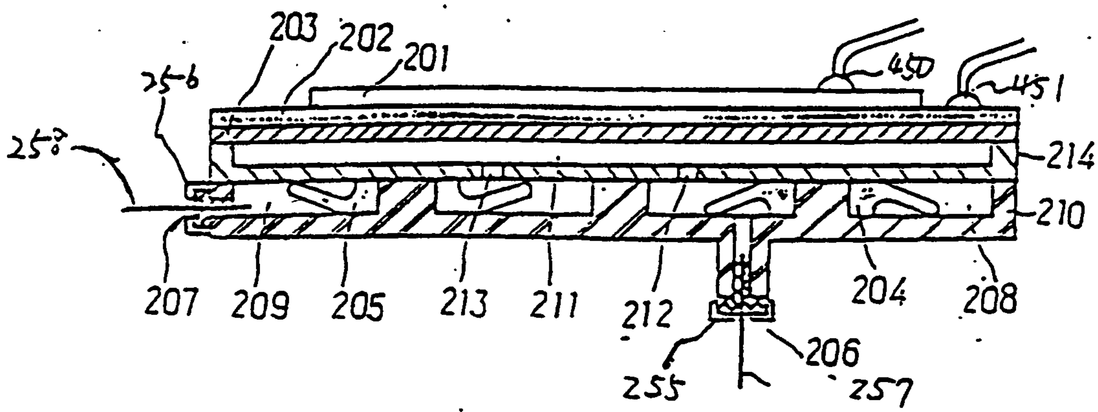


Fig.26

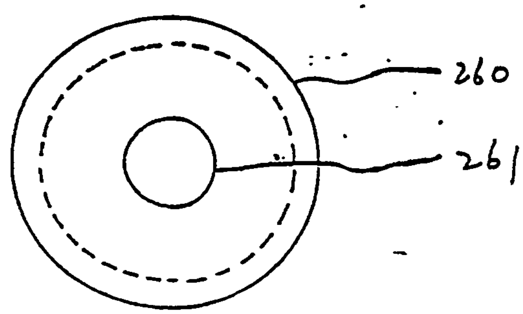


Fig.27

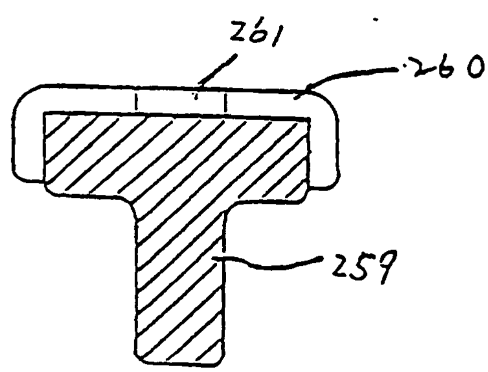


Fig. 28

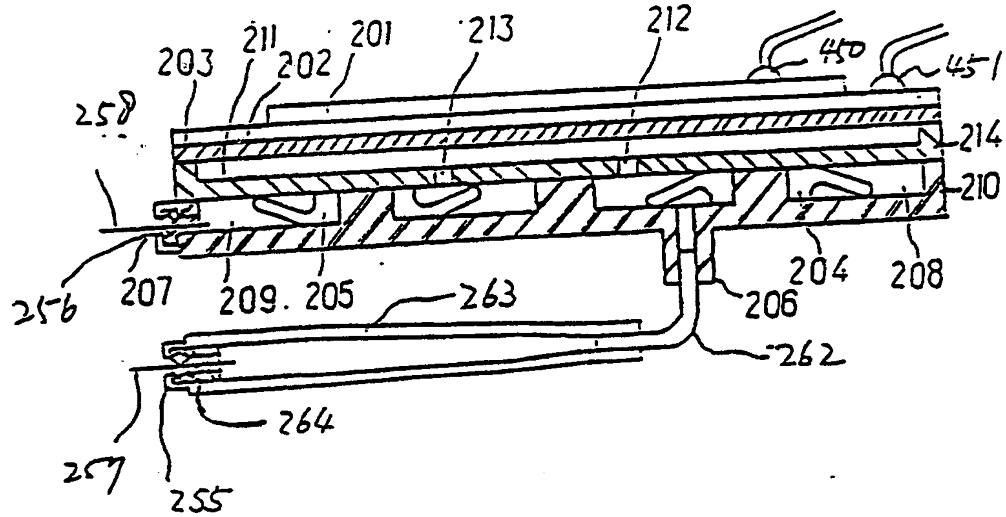

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Fig 29

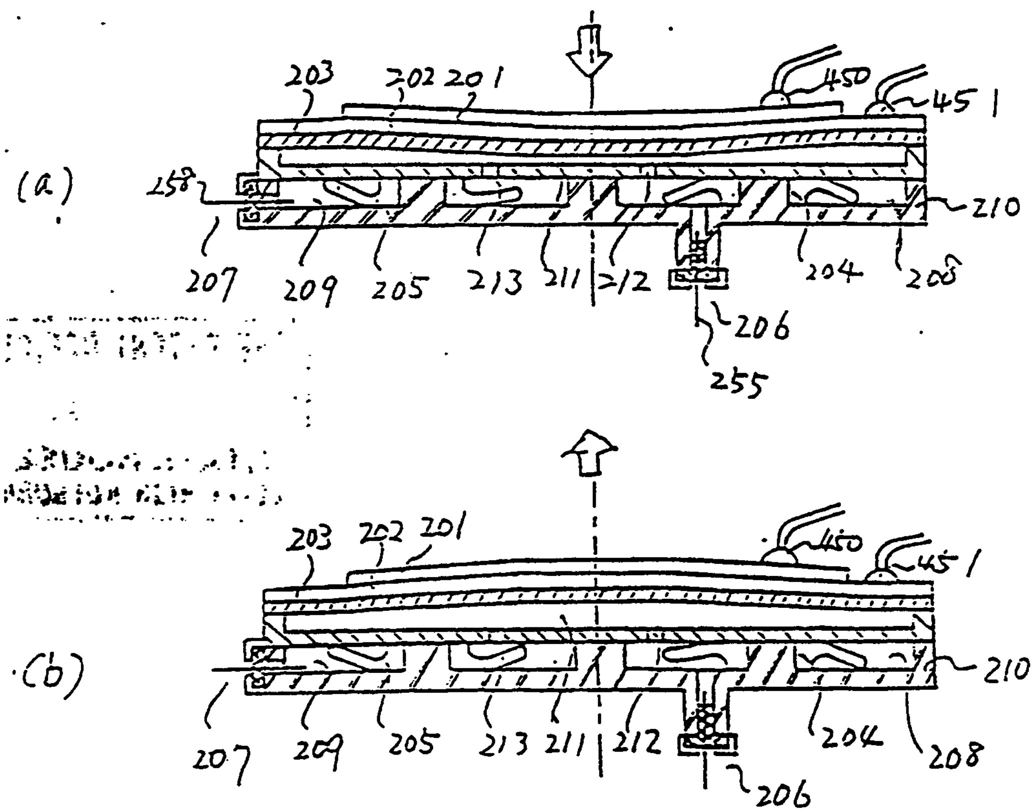
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FIG 30.

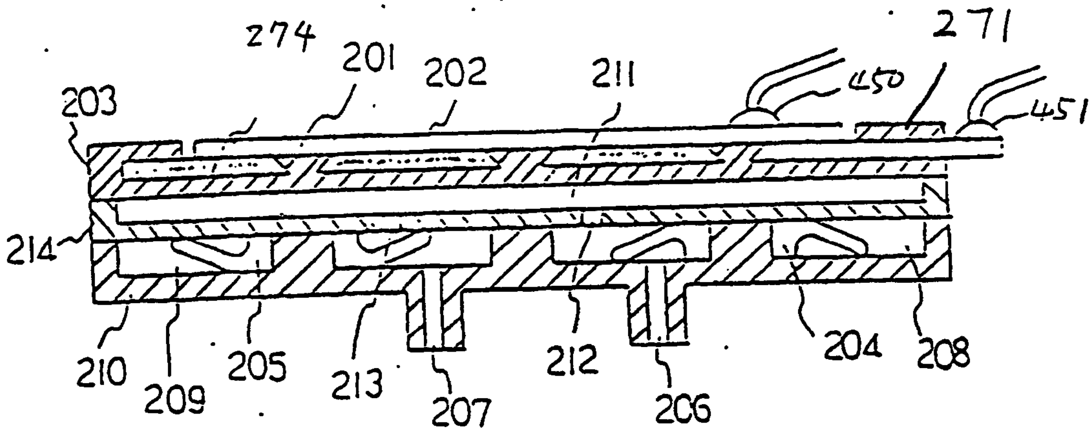

FIG. 31

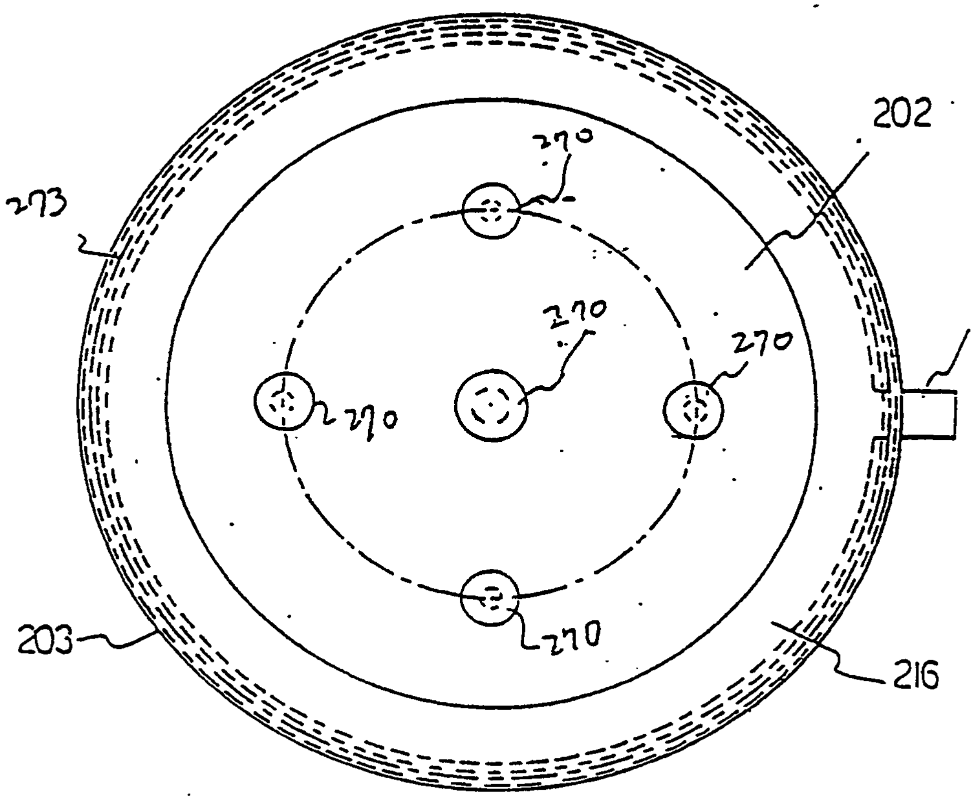

Fig. 32

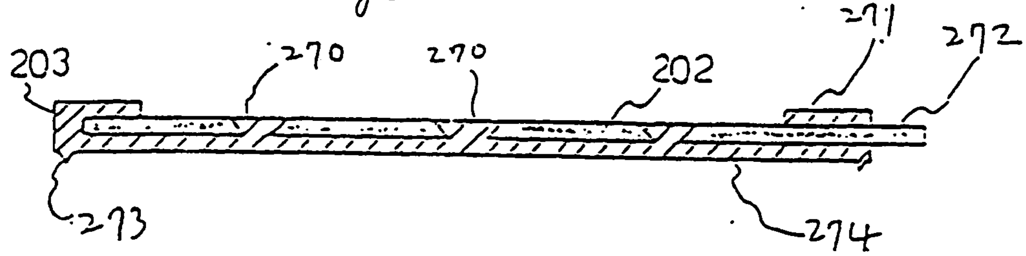

FIG. 33

(a)

(b)

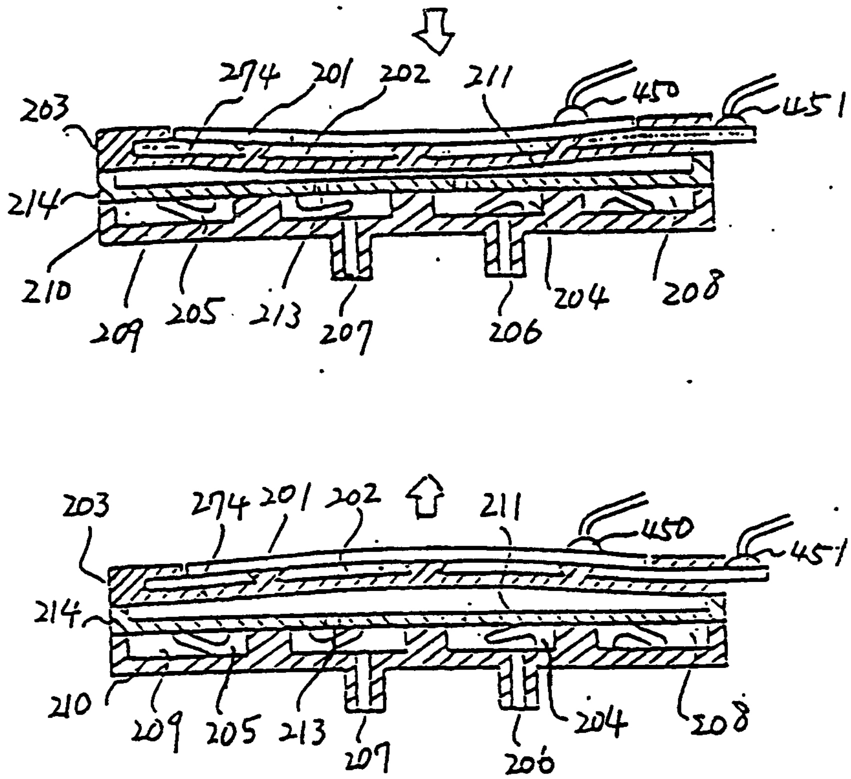

Fig. 34

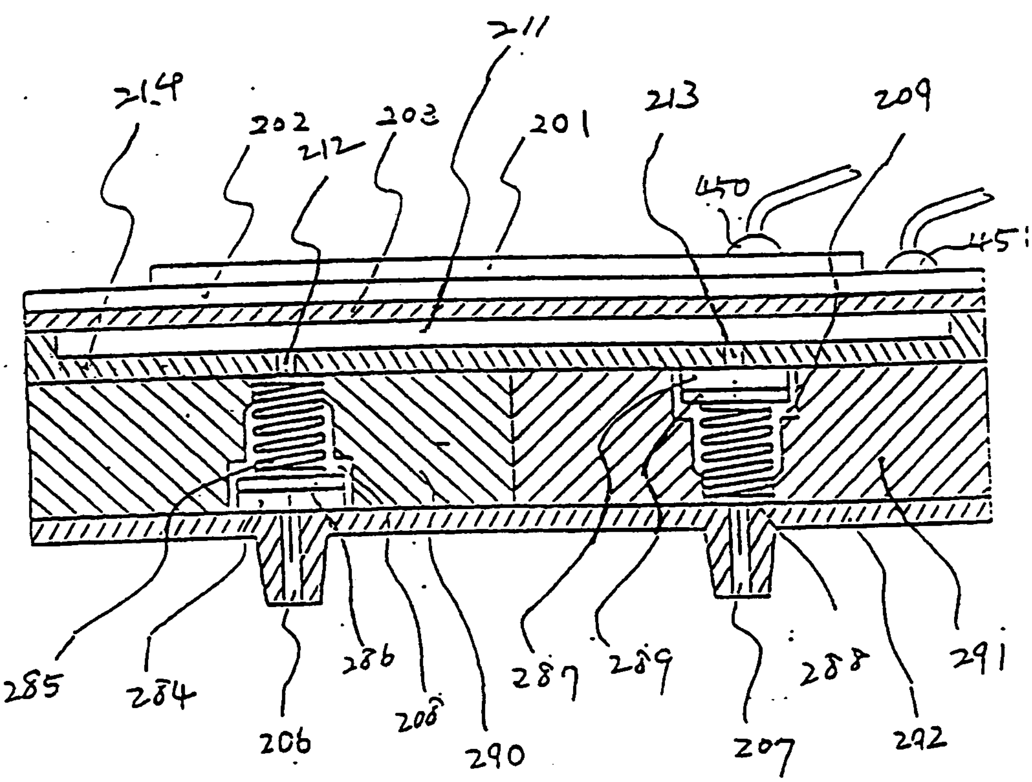

Fig. 35

(a)

(b)

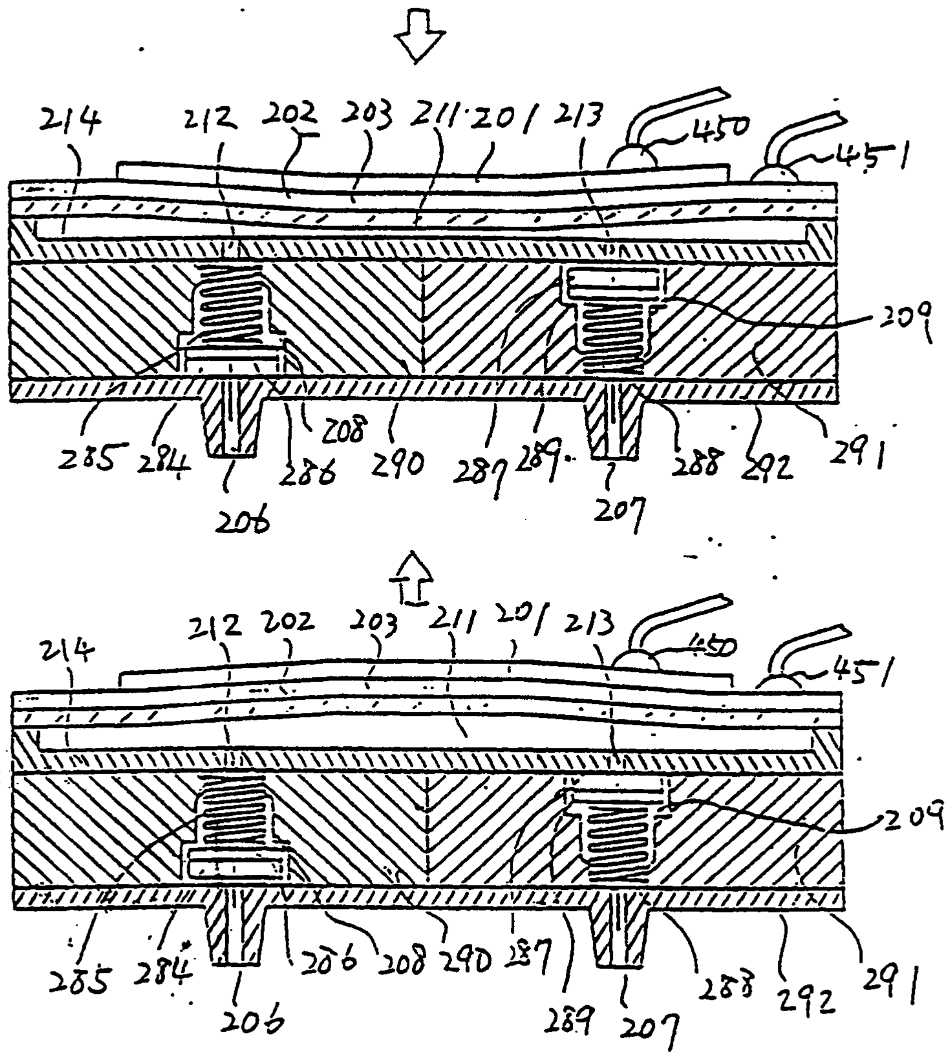
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FIG. 36

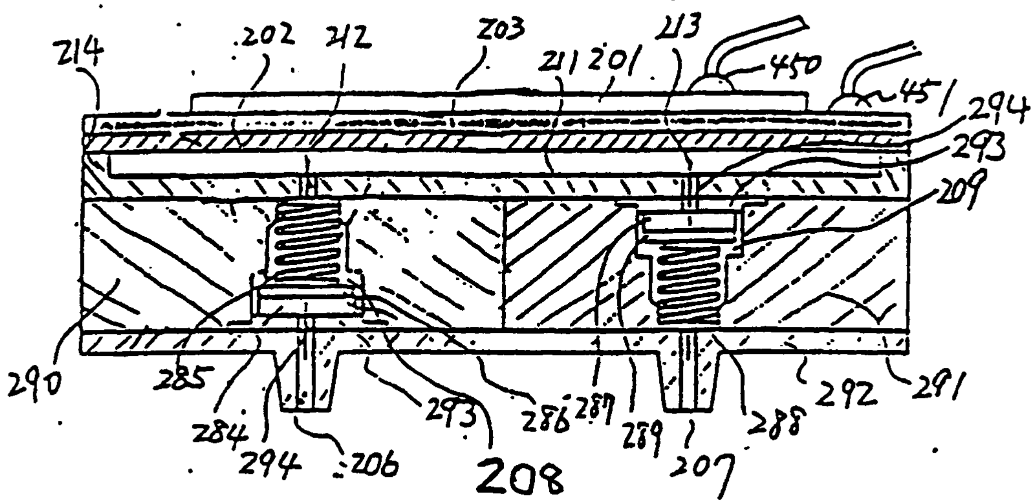
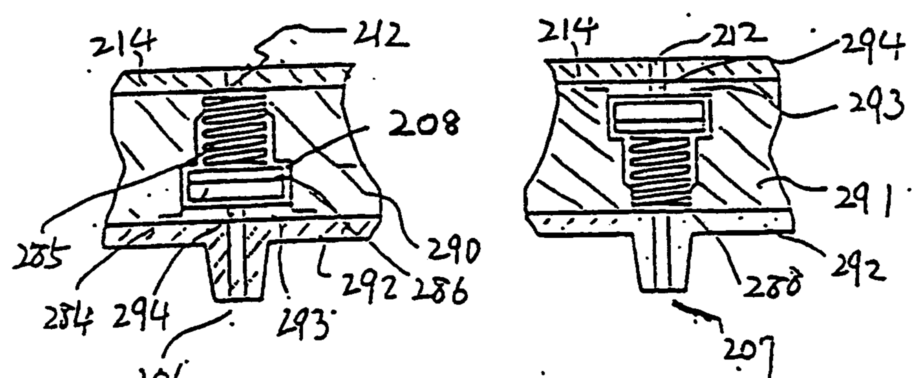
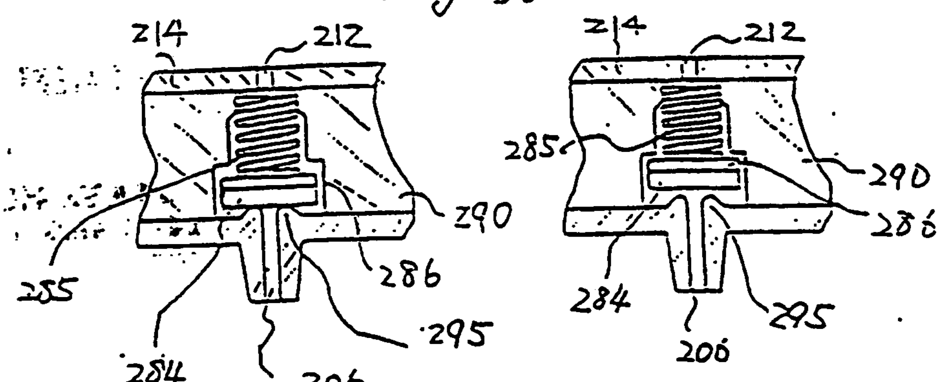


Fig. 37



(a) (b)

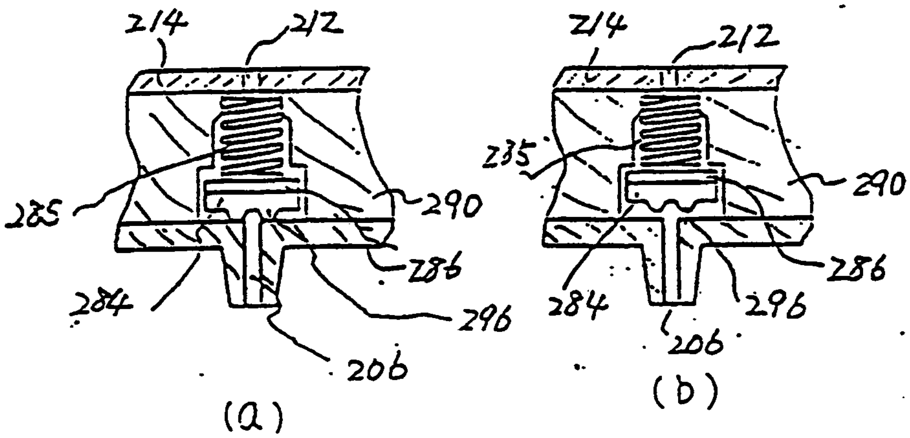
Fig. 38



(b)

(a)

Fig. 39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(a)
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(b)

Fig. 40

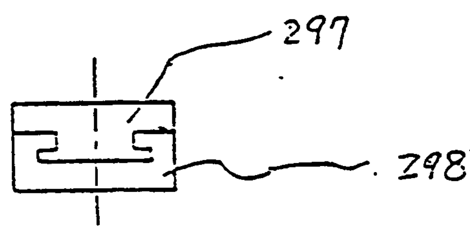
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Fig. 41

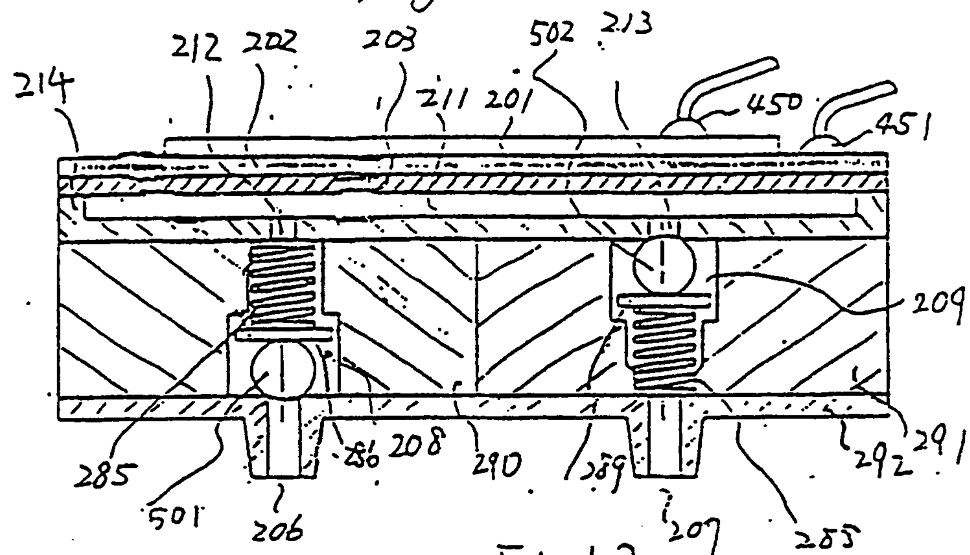


Fig. 42.

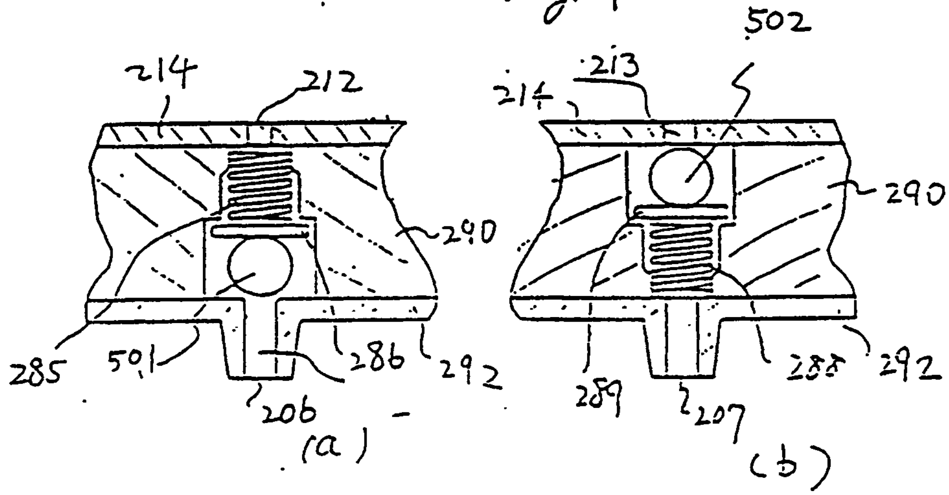


Fig. 43

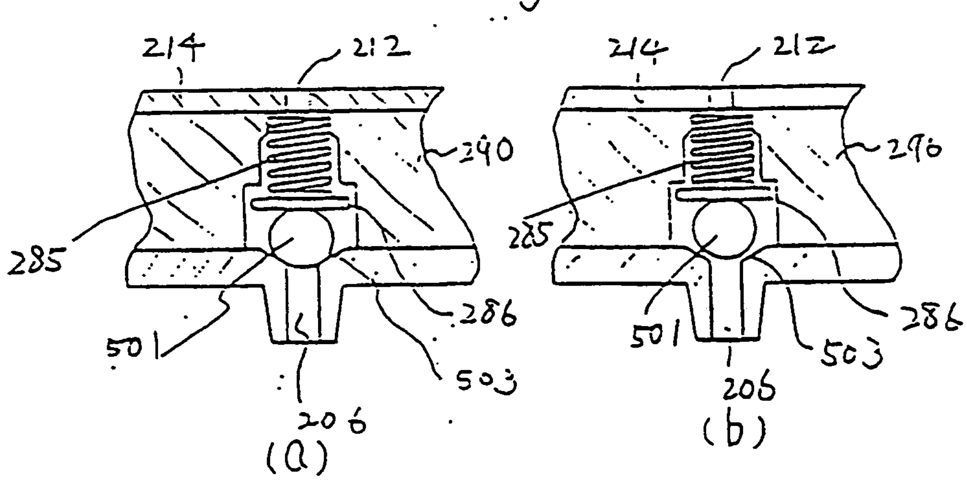


Fig. 44

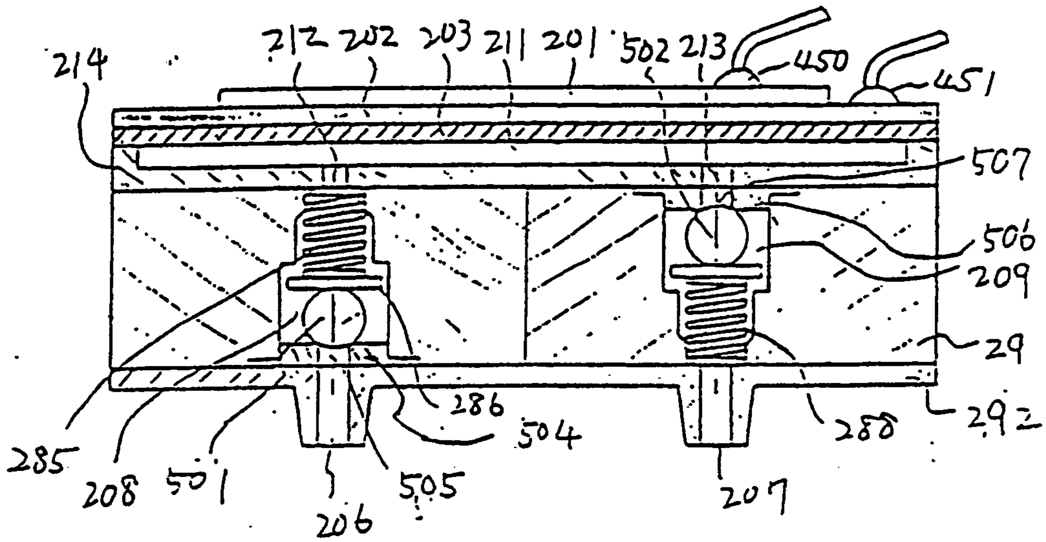
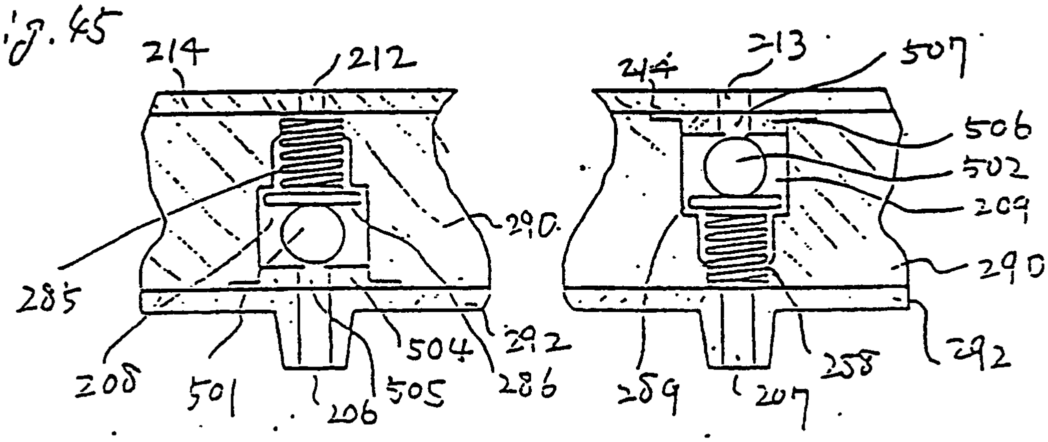


Fig. 45



(a) (b)

Fig. 46

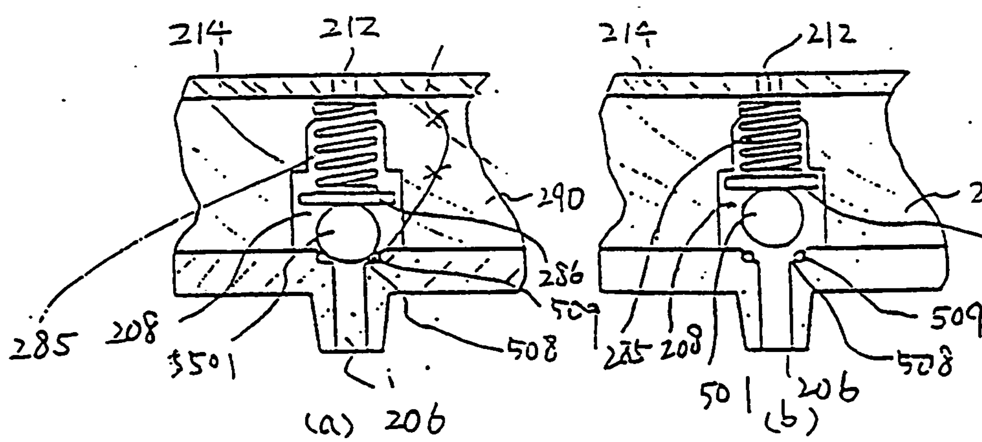
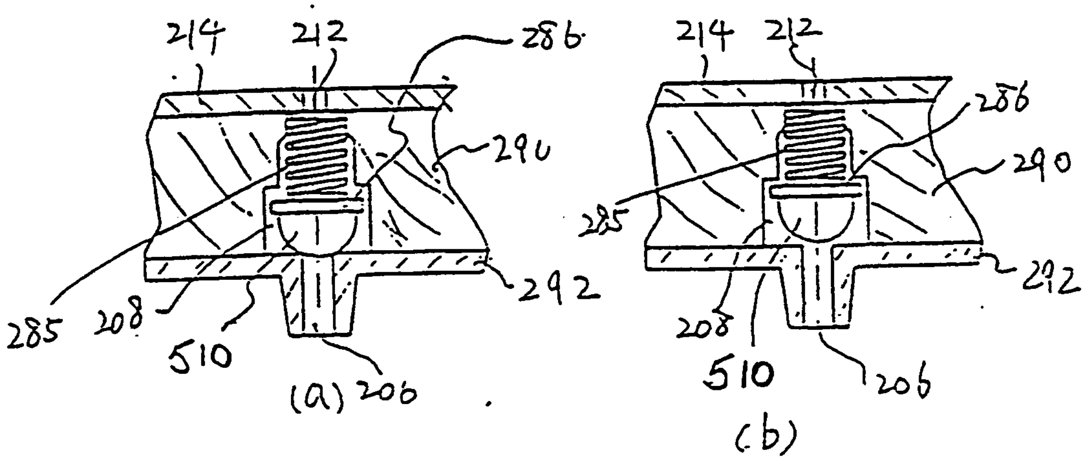


Fig.47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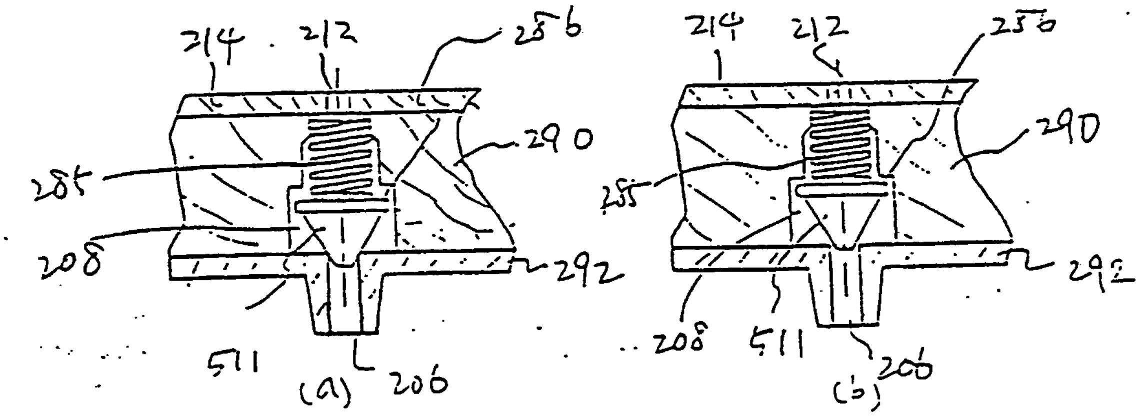
(b)

Fig.48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(b) 206

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 31 1316

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X,A	EP-A-0 322 899 (MISUZUERIE) * page 3, line 30 - page 4, line 20; figures 1, 2 *	1-5,17, 14,16,18	F 04 B 43/04 F 04 B 43/00 F 04 B 21/02 F 04 B 49/06
X	US-A-4 011 474 (O'NEILL) * column 2, lines 12 - 50 * * column 5, lines 7 - 63; figures 1, 5, 6 *	1-5,17	
X,A	US-A-4 596 575 (ROSENBERG) * column 2, line 29 - column 4, line 39; figures 1, 2 *	1-4,18,12	
X,A	PATENT ABSTRACTS OF JAPAN vol. 011, no. 392 (M-653) 22 December 1987, & JP-A-62 159778 (FUJI ELECTRIC CO LTD) 15 July 1987, * the whole document *	1-4,6-8, 10,11	
X,A	SENSOR AND ACTUATORS. vol. 15, no. 2, 15 October 1988, LAUSANNE CH pages 153 - 167; VAN LINTEL: "A PIEZOELECTRIC MICROPUMP BASED ON MICRO-MACHINING OF SILICON" * the whole document *	1-4,13	
X,A	WO-A-8 805 314 (KABIVITRUM AB) * page 4, line 21 - page 6, line 12; figures 1-3 *	1-4,18, 6-8,12	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

F 04 B
A 61 M

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	17 January 91	BERTRAND G.

CATEGORY OF CITED DOCUMENTS

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L: document cited for other reasons
&: member of the same patent family, corresponding document